PULVERIZED FUEL

ITS USE AND POSSIBILITIES

BY

WILLIAM J. DICK, M. Sc.

Commission of Conservation
Canada

COMMISSION OF CONSERVATION
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COMMITTEE ON MINERALS

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Commission of Conservation

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USE OF PULVERIZED FUEL

GENERAL FUEL SITUATION IN CANADA

IN a country of such enormous proportions as the Dominion of Canada, extending from the Atlantic to the Pacific, and northward to the Arctic, and with its severe winters, the question of an adequate fuel supply as a source of heat, light and power, and for use in the metallurgical industries, must always be of paramount importance. To a great extent the requisites of power and light can be supplied by the utilization of the numerous waterfalls with which the country is so abundantly supplied. Based upon investigations by the Commission of Conservation, the total water-power in Canada is estimated at 18,953,000 horse-power.[1] Assuming that, under average conditions, one horse-power-hour can be produced in a steam plant from three pounds of coal, one-half of the 17,000,000 horse-power, if developed, would, on a basis of twelve hours a day, and a load factor of 50 per cent, represent a saving of nearly 24,000,000 tons of coal per year. Although hydro-electric energy will, where available, to a great extent replace the use of coal for light and power purposes and for certain metallurgical work, the necessary uses of coal will continue on a large scale.

The coal deposits of Canada, in respect of quality, quantity, and accessibility for mining purposes, compare favourably with those of other countries. About one-sixth of the coal resources of the world is possessed by Canada. The deposits are, however, confined to the eastern and western portions of the Dominion, the large central market being supplied by imported coal. Previous to the war, Nova Scotia bituminous coal was used as far west as Montreal, while United States bituminous was sold within the area extending from Montreal to Swift Current and Saskatoon, Sask., the railways being the principal users of this fuel. Portions of Manitoba and Saskatchewan are supplied with coal also from Crowsnest, Lethbridge, Canmore, Drumheller, Edmonton, Yellowhead Pass and Souris districts.

Eastern Canada possesses no deposits of anthracite, and, as this class of coal is suitable for heating and domestic purposes, considerable quantities are imported from the United States. Prior to the war, it was sold over an area extending from Nova Scotia to Battleford, Sask., in the west. In 1913, imports exceeded 4,640,000 tons, more than double those of 1906; thus it is apparent that the demand for anthracite is rapidly increasing, notwithstanding the upward tendency of prices. The supply of anthracite coal in the United States, also, is limited, and there is no assurance that its

[1]Not all the water-power can be economically developed. This estimate was made by Mr. Arthur V. White, Consulting Engineer, Commission of Conservation.

export to Canada will be long continued. If mined at the present rate, the anthracite coal reserves of United States will be exhausted in about 100 years. We may, therefore, expect the price to gradually increase, until only the wealthy can afford it. Coincidently with the rising price, production will decrease, thus prolonging the life of the mines. Thus, during the four-year period, 1913-16, production decreased from 91,524,922 tons in 1913 to 88,312,000 tons in 1916, or rather more than one per cent per annum.

Of the total consumption during 1916, 45 per cent was domestic coal and 55 per cent imported coal, or, in other words, we imported more coal than we produced. The importance of this fact may be more fully recognized when it is realized that the value of the coal production, in 1916—$38,857,557—greatly exceeded that of any other mineral, and amounted to nearly 22 per cent of the total mineral production of Canada during that year. Although we have over 17 per cent of the world's reserve of coal, our production is small, and we import more than we produce.

It is desirable that these conditions be changed, both from the mining and national standpoint. If the United States was unable to export hard or soft coal to Ontario and Quebec or if they placed an embargo on its exportation, what would happen? In the spring of 1918 we had a slight example, when some of our educational institutions were forced to close their doors because of the shortage of coal, due to a temporary freight blockade.

From the above it is evident that, before many years, Canada may have difficulty in procuring supplies of anthracite coal from the United States, except at a greatly increased cost; also, as we have no supplies of this class of coal east of the Rocky mountains, we cannot supply the need from our own resources. We arrive at the conclusion, therefore, that, to take its place, some kind of substitute, of which we have large reserves, must be developed.

The following conditions have to be dealt with:

(1) Domestic fuel problem in Ontario and Quebec.
(2) Imported bituminous coal used as fuel on railways and as a source of power in Ontario, Manitoba and Saskatchewan.
(3) Domestic fuel problem in Prairie Provinces.
(4) Cheap power problem in Prairie Provinces.

(1) The following solutions of the domestic fuel problem in Ontario and Quebec are suggested: (*a*) By the installation of by-product coke-ovens at certain points on the St. Lawrence and Great Lakes system, the coke being used for domestic purposes in place of anthracite coal; (*b*) by the development of a peat industry, where peat deposits are near the market for such fuel; (*c*) eventually, electric energy will, to a limited extent, replace coal for heating and cooking purposes

(2) The establishment of the distribution system of the Ontario Hydro-Electric Power Commission has been effective in largely replacing

imported coal as a source of power in Ontario by electric energy derived from our water-powers. But for the work of this commission, many industrial plants in Ontario would have been hampered during the war, if not forced to shut down, for lack of power.

The economic solution of the railway fuel problem may be secured by the electrification of our railways which, for obvious reasons, would be undertaken step by step. So far as certain portions of the Prairie Provinces and Western Canada are concerned, the problem may be solved by the use of pulverized lignite or sub-bituminous coal, by the use of briquetted fuel made from lignite or bituminous coal, and by the increased use of our own bituminous coal, which is equal in every respect to that imported.

Consideration of this problem of importing coal requires that it be discussed under two headings, *viz.:* "Anthracite Coal" and "Bituminous Coal".

Anthracite Coal—This domestic fuel is a luxury, not a necessity; the higher grades of sub-bituminous and lignite coals can be used in its place, and have several advantages over hard coal. In 1918-19, for the first time, Winnipeg used western coal to a very considerable extent, and it gave good satisfaction, notwithstanding the fact that most people were not familiar with the manner in which it should be used.

Bituminous Coal—The imported bituminous coal is used largely for railway use, but a portion is also used for ordinary power purposes.

The value of the imports of coal into Fort William, Port Arthur, and Manitoba ports of entry amounts to from $14,000,000 to $18,000,000 annually. This figure represents actual money that goes out of the country. This money would otherwise be spent in developing Western Canadian industries.

That American coal is used to such an extent, particularly by the railways, is due to the fact that the United States coal is hauled from the lake ports to the western markets in cars which have been used for hauling grain. This, nevertheless, curtails the markets for Canadian coals. Transportation conditions on our railways during the winter months, from September 1st to February 1st, are not desirable, because, during that period, the railways have two superimposed peak loads, *viz.*, the grain haul from the west, and the coal haul from Canadian mines, which amounts to several millions of tons. The railways must, therefore, have double the rolling stock and equipment that would otherwise be necessary. In fact every year there is a scarcity of cars available for the movement of grain and coal.

The problem, which must be solved, therefore, is briefly this: How can Canadian coal be used in place of imported coal, without costing the consumer more, and at the same time solve the transportation problem? The answer to this problem and the putting of it into practice will mean twice the number of men employed in the coal mines in the west, and, at the same time, retaining in the country the large amount of money above mentioned.

The coal mines of Alberta and Saskatchewan have a capacity for producing some 15,000,000 tons of coal per annum. This fact is of importance when it is considered that the actual production of coal in these provinces in 1918 did not exceed 6,319,663 tons. There is no doubt, even under existing conditions, but that the production could be increased some 4,000,000 tons if the demand should warrant it.

The enlargement of the markets for western coal would also be the means of reducing the price of this coal to the consumer. For example, practically all the domestic coal-producing mines in Alberta are closed down from March 1 to August 15, which means that the fixed charges during this period must be borne by the coal produced during the autumn and winter.

Actual operation shows that, in the same time, operating at 50 per cent capacity as against 85 per cent capacity, the cost of production per ton of coal amounted to over $1.10.

This situation could be improved by the Government carrying out the recommendation made by the Conservation Commission* that a supreme engineering authority be appointed, with full powers to prevent the use of wasteful methods in the mining of coal; also by the stocking of coal during the summer months.

Under present conditions dealers will not stock coal during these months, owing to additional costs necessary to cover carrying charges, etc. A dealer who stocks coal also has to compete with those who deliver direct from the cars during the winter. There are, therefore, no inducements offered for stocking coal.

In order to secure a more equable distribution during the entire year, and thus relieve the car shortage which occurs in winter, while at the same time permit of the working of the coal mines during the summer months, it appears desirable that special freight rates should be granted on coal shipped eastward during this period and also that the mines should give special summer prices for coal. The differential between the cost of summer and winter coal should be great enough to encourage not only the dealers to stock up, but also to induce consumers to lay in their winter supplies.

It is of first importance also that an investigation be carried out by the Government to determine what special processes could be applied to the more economical use of the low-grade fuels in Alberta and Saskatchewan.

In a report, *Conservation of Coal in Canada*, published by the Commission of Conservation, in 1911, the briquetting of the lignites of the west was advocated to obtain the above conditions. One of the first problems considered by the Honorary Advisory Council for Scientific Research was the possibility of the briquetting of carbonized lignite. Indications point towards the establishment by the Dominion Government, in conjunction with the Governments of Saskatchewan and

**Conservation of Coal in Canada*, Commission of Conservation, 1914, pp. 3-5.

Manitoba, of a commercial plant to demonstrate the practicability of the process. Should the result be satisfactory, it will not only provide a suitable fuel for the farmers in place of imported anthracite coal, but will cause a great development of the coal-mining industry of Saskatchewan.

Distribution of Imported Coal

As the coal-fields are situated in the eastern and western portions of Canada, the interior portion, from Cornwall, Ont., on the east, to Swift Current, Sask., on the west, is supplied by coal from the United States. The central and eastern portion, comprising central and eastern Ontario, is supplied *via* St. Lawrence, Lake Ontario and Niagara River ports; coal for the west is hauled by rail to Buffalo and Lake Erie ports, whence it is carried by water and rail to its destination. The bituminous coal is used principally for railway and the anthracite for domestic purposes.

Table I shows the imports of coal into Ontario and Quebec. Tables II, III and IV show the imports of coal into Fort William, Port Arthur, Fort Frances and Manitoba, Saskatchewan and Alberta ports of entry.

TABLE I—IMPORTS

	Bituminous coal, in tons					
	1913	1914	1915	1916	1917	1918
Ontario...	10,021,334	11,874,793	7,938,042	8,696,181	10,196,990	12,091,932
Quebec....	796,401	1,558,792	1,558,792	1,025,220	2,571,806	3,860,721

	Anthracite coal, in tons					
	1913	1914	1915	1916	1917	1918
Ontario...	2,861,073	2,946,468	2,912,187	2,945,358	3,086,622	3,362,322
Quebec...	1,151,634	1,167,660	1,217,459	1,224,534	1,251,283	1,719,870

TABLE II—Imports of Anthracite Coal

	1913	1914	1915	1916	1917	1918
Fort William.....	294,162	376,835	316,744	194,225	378,189	386,109
Port Arthur......	167,705	205,380	146,207	86,390	121,654	170,315
Manitoba........	17,321	29,719	22,274	37,409	21,503	12,290
Saskatchewan....	43	111	105	40	32	1
Alberta..........	21	119	....		....	....
Totals.......	479,252	612,164	485,330	318,064	....	....

TABLE III—Coal Imports—Bituminous Slack, such as will pass a ¾-inch Screen.

	1913	1914	1915	1916	1917	1918
Fort William......	41,630	91,758	136,435	152,873	179,815	214,380
Port Arthur.......	3,641	16,954	29,347	12,884	8,101	43,715
Fort Frances.....	....	....	....	15,440	20,680	22,477
[1]Manitoba.........	46,092	36,785	56,587	45,296	50,911	25,856
Saskatchewan.....	340	298	174	697	91	562
Alberta...........	691	165	224	254	144	815
Totals....	92,394	145,960	222,767	227,444	259,742	307,805

TABLE IV—Coal Imports—Bituminous Round and Run-of-mine, and Coal N.O.P.

	1913	1914	1915	1916	1917	1918
Fort William......	1,568,936	1,966,458	897,470	915,471	1,095,128	1,500,034
Port Arthur.......	961,722	1,002,368	641,293	697,239	860,149	779,314
Fort Frances.....	....	....	....	46,638	50,345	83,812
[1]Manitoba.........	69,011	23,434	46,898	65,351	47,737	378,199
Saskatchewan.....	1,823	2,803	460	334	223	298
Alberta...........	59	118	499	567	67	115
Totals...	2,601,551	2,995,183	1,586,620	1,725,600	2,053,649	2,742,772

The coal brought up the Great lakes is carried as return freight in ships engaged in the ore-carrying trade. Owing to the higher wages paid the miners and higher transportation charges, industries in Canada dependent on United States coal are handicapped. The increase of prices will tend to increase the distribution of Canadian coal farther east and make possible the development of uses for inferior coal.

The most important users of imported coal are the railways and transportation companies.

Railway Fuel

One of the most important factors in locomotive haulage is that of a suitable and economic fuel. The extent to which coal is thus used in Canada is shown by the following table:[2]

Year	Tons of coal	Cost
1912...	7,783,736	$24,160,823
1913...	9,263,984	28,426,355
1914...	8,547,675	26,710,758
1915...	6,903,418	20,889,055
1916...	8,995,123	27,961,186
1917...	10,130,799	36,784,642
1918...	10,173,344	52,630,430

[1]Probably a considerable portion was all-rail coal via Emerson and Gretna, Man.
[2]*Railway Statistics*, Department of Railways and Canals, 1918, p. xxx.

The tonnage of coal used annually on railways in Canada is equivalent to nearly 68 per cent of our total coal production for same period. In 1918 the coal production of Canada was 14,977,926 tons, while in the same year the railways consumed 10,173,344 tons of coal. In addition, 52,507,528 gallons of fuel-oil was used as locomotive fuel. The oil was imported from the United States and represented the equivalent of 312,545 tons of coal.

The development of fuel-oil, for use on railways and steamships, has resulted from the discovery of large oil-fields in California. Oil fuel has many advantages over coal, but its use or non-use will largely depend upon whether it is the most economical fuel under the circumstances. Railway companies have adopted it, not on account of any compulsion on the part of the Government, but from business considerations. On account of the ease with which it can be loaded into boats and fired, and because it occupies less space than coal, thereby giving greater freight-carrying capacity to steamships, it will be used on this class of traffic even after its price exceeds the price of its heat-equivalent in coal.

Fuel-oil has been used to a considerable extent on railways in the United States since its introduction in 1900. The partial exhaustion of adjacent oil-fields has caused some of these lines to revert to coal. The reversion will be still more evident as the increasing prices for oil offset its advantages. The use of fuel-oil in Western Canada will depend upon the low price of crude oil from California or other states bordering on the Pacific and from Mexico. With regard to this subject, David T. Day, in *The Production of Petroleum in 1913*[1], states: "In California the railways were the first to absorb large quantities of California oils. This legitimate use has become permanent from lack of other fuel, and it has extended to other kinds of generation of power, including marine transportation for shipments coastwise and to foreign countries. *A serious menace to the continued use of oil for fuel in California*[2] is the recent change in the character of the crude oils of that state. Many of the new pools yield oils suitable for refining and for the production of large quantities of gasolene and kerosene. Up to the beginning of 1913, about 30 per cent of the oils of California was refined and the rest was sold for fuel, as crude, or after very slight distillation of the lighter products. This practice changed materially during 1913, so that the proportion of crude oil used direct as fuel became reversed, and, although no accurate figures are available, 70 per cent is about the proportion of crude oil which was refined during that year, before the heavier portions were sold for fuel. The result of this, however, will be, not to decrease the use of oil for fuel, but to change the method of its application, particularly to the internal-combustion engine burning kerosene and heavier distillates". It is another significant fact that in 1915 the number of producing wells was increased, but the average yield per well per day dropped from 47 barrels

[1]Mineral Resources of the United States, p. 952.
[2]The italics are the writer's.

in 1914 to 39 barrels in 1915. Although the petroleum business in California during 1915 was poor, and the price of oil one and one-half cents per barrel less, this was due largely to the effects of the war. The price, however, will increase for the above reasons, and there will be a greater demand for it for steamship use, incident to the placing in full operation of the Panama canal. The writer is of the opinion that, in so far as Canadian railways are concerned, the economic advantages of fuel-oil for locomotive use over that of Canadian coal is more favourable now than will be the case in the future. Should this prove to be the case the railways will, no doubt, for economic reasons, revert to the use of coal.

The coal reserves of Canada are considerable, but a large proportion is unsuitable for use in the ordinary way as locomotive fuel. The coals of Manitoba, Saskatchewan and portions of Alberta are lignite or sub-bituminous, high in moisture, and cannot be used as locomotive fuel on account of the liability of setting out fires from excessive sparking.

In 1913, the Board of Railway Commissioners issued an order[1] calling upon the railways to equip their locomotives with fire-preventive devices, to discontinue the use of certain grades of lignite coal on their locomotives, and to guard against outbreaks of fire along their rights-of-way.

In so far as supplies of fuel are concerned, the eastern portion of Saskatchewan forms the competitive area between the United States coal, on the one hand, and the high-grade bituminous coal of the Rocky mountains and adjacent region, on the other. It is evident, therefore, that the cost of fuel in this portion of the province is high. On account of our large imports of coal and fuel-oil, which, under these circumstances, are costly fuels, anything that can be done to increase the efficiency of generating power from coal or economically curtail the use of fuel-oil by the substitution of coal or lower-grade fuels which formerly could not be used on account of their liability of setting out fires from sparks, should be welcome.

PULVERIZED FUEL

History

Nearly a century ago pulverized coal as a fuel was experimented with, but its application to industrial purposes really commenced in 1895, when used in connection with the burning of cement. Its comparatively slow development was due largely to the fact that the advantages of thorough drying and fine grinding were not fully recognized. It was not until the pressing demands of the cement industry for a low-priced fuel of high efficiency became imperative that pulverized coal was found almost ideal. In this industry it is essential to grind cheaply the cement materials to a high degree of fineness so that the pulverizing of coal fell naturally into the hands of men able to powder cheaply, and to the same consistency, a material much less resistant than cement rock or clinker. The next general

[1]*General Order No. 107*, Board of Railway Commissioners, July 14, 1913.

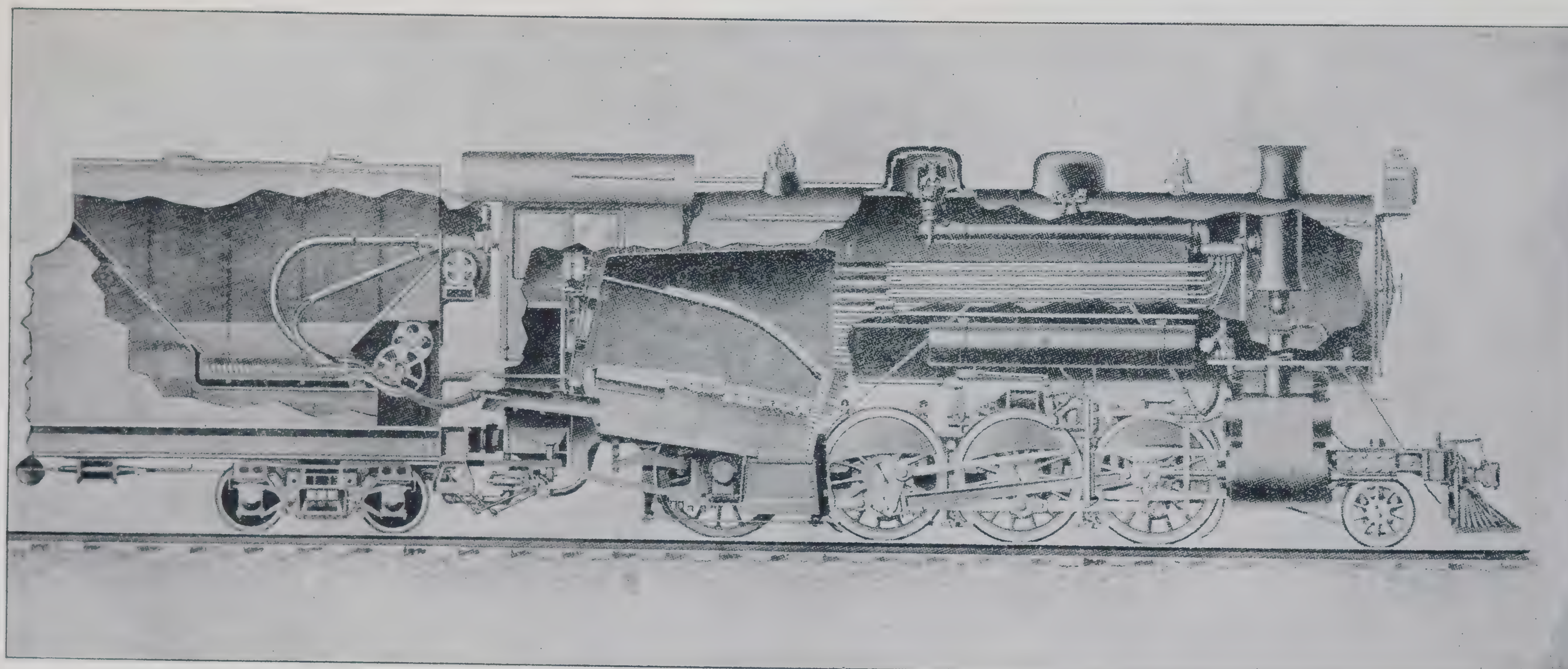


DIAGRAM INDICATING EQUIPMENT FOR BURNING PULVERIZED FUEL IN STEAM LOCOMOTIVES

application of this fuel was in certain metallurgical processes, such as a source of heat for simple furnaces, where excessive temperatures were not required and where the ash deposits were either continuously removed with the heated material or could readily settle on the hearth and be withdrawn.

About sixteen years ago, the Manhattan Elevated railroad experimented with pulverized coal as a fuel on one of its locomotives. The equipment consisted of a combined pulverizer, blower and steam turbine situated on the locomotive. It is understood that, as the coal was not ground sufficiently fine, and because certain mechanical details were not provided for, this method of burning coal was not successful.

During the last few years the Swedish Government and Swedish Boiler Society have carried on tests, using pulverized peat as a fuel on locomotives and stationary boilers, which have resulted in the successful use of this class of fuel.

In 1914, the New York Central railroad placed in operation a locomotive, of the ten-wheel type, having a tractive power of 31,000 pounds. This was the first locomotive of any size to be equipped and successfully operated for burning pulverized coal in suspension. Since then a similar application was made to an Atlantic-type locomotive of the Chicago and Northwestern railroad. Early in 1917 the Delaware and Hudson railroad installed the first complete commercial plant for supplying pulverized coal to one of its locomotives operating in regular train service.

In 1906 coal dust was experimented with in connection with reverberatory copper smelting at the Highland Bay smelter. While these experiments did not lead to its final adoption at this smelter, the results obtained showed very clearly that increased tonnage, with decreased fuel consumption, could be attained, and that such difficulties as were encountered were largely mechanical and presumably removable. In 1909 the use of pulverized coal as a fuel was investigated by Messrs. David H. Browne and Geo. E. Silvester, of the Canadian Copper Co., and, as a result, it was decided to install coal-dust firing in connection with the reverberatory smelting of copper-nickel ore and flue-dust at their smelter Copper Cliff, Ont. Construction of the plant was begun in 1910 and completed in 1911. After investigating the work of the coal-dust fired reverberatories of the Canadian Copper Co., the management of the Washoe Reduction Works, Anaconda, Mont., decided to experiment with and ascertain the advantages of using coal-dust as a fuel in their reverberatories. In 1914 a reverberatory furnace was remodelled to use pulverized coal as a fuel, and the results obtained showed a decided saving in cost of smelting, as compared to grate-firing with lump coal.

In 1912 the American Iron and Steel Manufacturing Co. had carried its experiments to a point where it was ready to publish statements of the successful uses of this fuel. In their plant at Lebanon, Pa., pulverized

coal was used as fuel for puddling furnaces and small reheating furnaces for nut, bolt and spike bars, and in large furnaces for continuous billet-heating and open-hearth melting.

During the last few years pulverized coal has also been successfully used in stationary boilers. In 1913 the Dominion Coal Co. installed Bettington boilers, burning pulverized coal, in connection with its power plant at New Waterford, N.S. This was the first installation of its kind in North America.

PULVERIZED FUEL IN BOILER PLANTS

The development of the use of pulverized fuel in stationary boiler practice is of much later occurrence than its use as a metallurgical fuel. The early experimenters did not appreciate the necessity of fine grinding, nor the influence of furnace design upon the temperature of the resulting gases, consequently trouble was experienced through the action of the high temperature flame upon the brickwork. The blow-pipe effect of the high-velocity jet tended to melt the brickwork. A layer of slag, formed by the fusing of ash and brickwork, accumulated in the bottom of the combustion chamber and discouraged those who depended upon this fuel for continuous service. Difficulty was also encountered in the minute particles of liquid slag being carried in suspension and deposited upon the tube-sheet or water-tubes of the boiler, therefore interfering with its operation.

The knowledge gained recently, both in experimental work and by experience in equipped plants, has shown that these difficulties can be, and have been, overcome. The economy secured by the use of pulverized fuel in stationary boilers, instead of hand-fired coal, is not as great, in comparison, as that derived from its use in locomotives. This is due, largely, to the fact that, it is possible to equip stationary plants with the best mechanical stokers. There is an advantage of two or three per cent in combustion efficiency in favour of pulverized coal, but this is offset by the additional cost of fuel preparation. While the above comparison is made from the standpoint of efficiency, and where almost similar coal is used, there are many localities, especially in Northern Ontario and portions of Manitoba, Saskatchewan and Alberta, where pulverized peat or pulverized coal could be used to decided economic advantage instead of higher-priced imported coal.

Bettington Boiler

Boiler Plants—This combined boiler and pulverizing plant is the result of a long and expensive series of experiments, commenced in South Africa, continued and first patented in United States, and finally completed and commercially exploited in Great Britain. A summary of the difficulties encountered in applying pulverized fuel to steam-boiler practice is presented as follows in the catalogue published in the interest of this boiler:

(1) The difficulty of maintaining continuous and steady ignition; a difficulty only met by maintaining a uniform and very high temperature in the furnace.
(2) The failure to find an economical material to stand the destructive temperature necessary in the furnace as hitherto arranged for boiler firing.
(3) The difficulty of producing a continuously homogeneous mixture with varying grades of coal, sometimes very wet, and high in ash.
(4) The difficulty of maintaining a homogeneous mixture of fuel-dust and air during the full period required for complete combustion; the tendency of the larger solid particles being to concentrate in certain lines of direction; a difficulty met in part by extremely fine pulverization of the fuel.
(5) Difficulty of handling the molten ash, which, from the required type of furnace and temperature, must usually form solid deposits of slag.

The essential features of this type of boiler are:—

(1) Pulverizer and blower.
(2) Dust-separator chamber.
(3) Water-cooled nozzle or tuyere.
(4) Vertical water-tube boiler.
(5) Air heater.

The coal is fed automatically to the pulverizer, which acts also as a blower. The air, before being drawn into the pulverizer, is heated by means of an air-heater placed in the path of the waste gases from the boiler. By pre-heating the air, coals containing up to 15 per cent moisture can easily be disintegrated and burned.

The coal, after being disintegrated, is delivered into the dust-separating chamber, the fines passing direct to the fuel nozzle and the coarser particles returning by gravity to the pulverizer for further reduction.

The fine coal delivered at the nozzle, and which, practically speaking, may be considered as a gas, is ignited and burns in the combustion chamber of the boiler. The heated gases pass from the combustion chamber up between the water tubes, through the economizer and air-heater, to the stack. The boiler consists of top and bottom headers, with solid drawn-steel tubes connecting them. Special bricks in combination with the innermost circle of tubes form the wall of the combustion chamber. No binding material is employed for these special bricks. The combustible matter in the fuel is said to be consumed and the residue is an irreducible vitreous slag. The slag solidifies at a relatively high temperature, and soon chokes up and hermetically seals all crevices, cementing the lining into one solid piece. The bulk of the slag falls into the ash-pit below. n the form of small globules which are easily removed, the quantity being very small in comparison to the ashes from an ordinary hand-fired boilei The steam, before passing to the turbines, is superheated by means pipes spirally wound around the boiler tubes.

For this type of boiler, the manufacturer claims the following advantages:

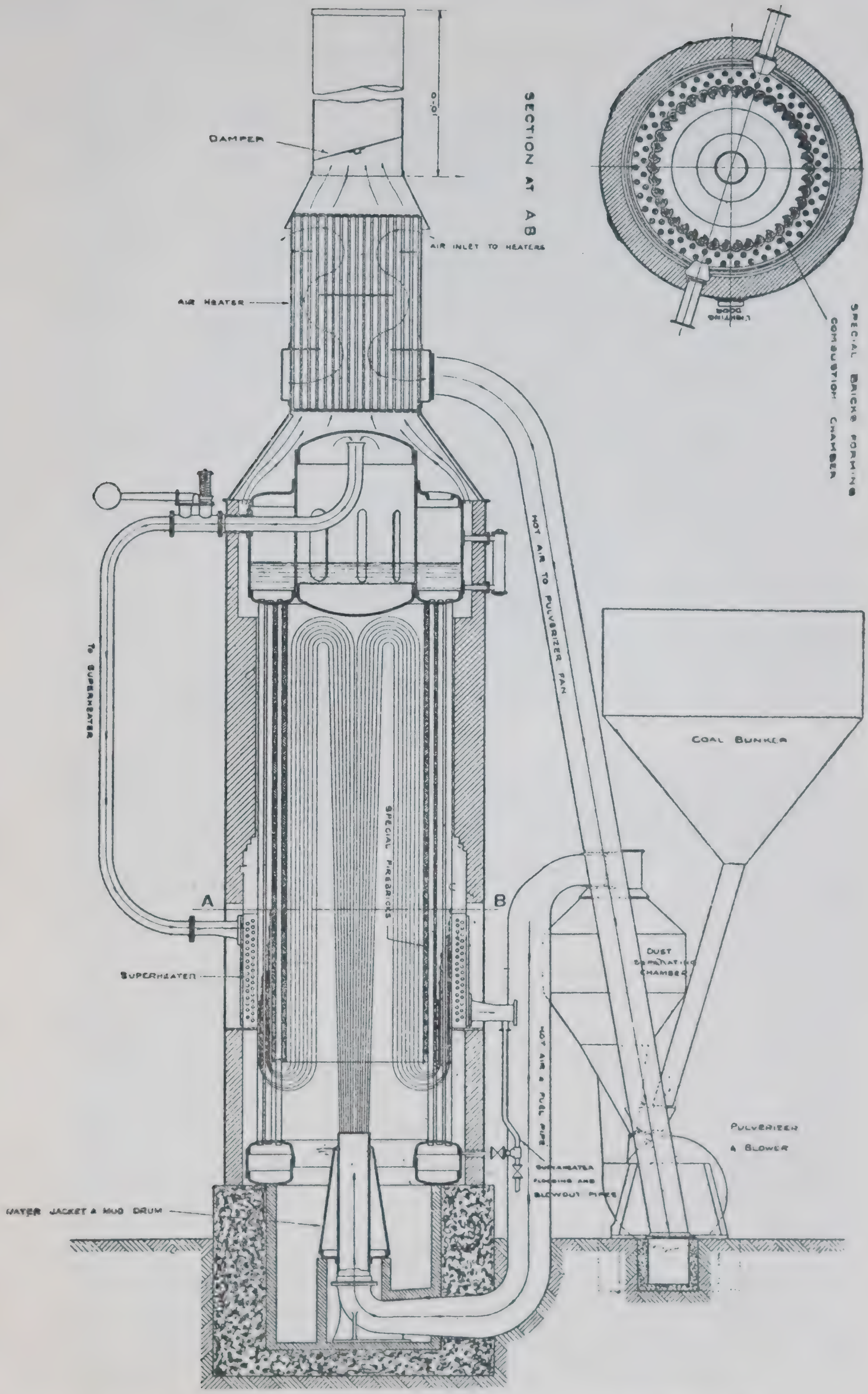
(1) The boilers will give an efficiency not given by any other boiler on the market.
(2) They can be fired at any desired rate by adjusting the feed of the pulverizer.
(3) They are easily cleaned.
(4) After being closed down for a time, full steam can be generated quickly.

In 1913 the Dominion Coal Co. installed in their plant at New Waterford, N.S., three Bettington boilers, each having a normal evaporation, from and at 212° Fahr., of 20,000 pounds per hour. They are fired with slack coal which could not be economically used to generate power in the ordinary boiler. This plant was the first of its kind to be installed in America. Other users of this boiler are the British Admiralty, Johannesburg municipal power station, Clifton and Kersley Coal Co., British Oil and Cake Mills, of London, Hull and Manchester, Erith Urban District Council, De Beers Diamond Mines, Donisthorpe and Co., Jupiter Gold Mining Co., Warren Hill Syndicate, Ltd., Crown Mines, Ltd., Bantjes Consolidated Gold Mines, Ltd., all of which, it is claimed, are securing the greatest satisfaction.

On page 15 is shown a sectional view of this boiler. The boilers are built in five standard sizes, with evaporations of from 6,000 to 40,000 pounds per hour, at normal evaporation from and at 212° Fahr., as follows: No. 1, 6,000; No. 1*a*, 8,000; No. 2, 12,000; No. 2*a*, 20,000; No. 3, 40,000 pounds per hour.

The following are the results of tests on this boiler, as outlined in the catalogue before mentioned:

Coal used	C.R.C. nuts	Dant		South African		Duff	Welsh anthracite duff
		Clifton and Kersley	Ellesmere	Partings	Pickings		
Analysis (on dry coal)—							
Ash	22·18	23·00	21·12	22·58	21·30	19·92	12·64
Volatile matter	25·97	20·00	26·46	27·38	27·68	22·94	11·66
Sulphur	....	....	3·13	0·85	0·95	0·76	0·99
Fixed carbon	51·85	57·00	52·42	50·04	51·02	57·14	75·70
Calorific value on dry coal (B. t. u.)	8,710	10,700	11,250	10,098	10,494	11,088	12276
Calorific value on dry coal (B. t. u.), expressed as pounds of water, evaporated from and at 212° Fahr.	9·01	11·08	11·65	10·45	10·86	11·48	12·71
Absolute steam pressure, pounds per sq. in.	140	164·5	164·8	152·3	152·15	130·45	151·1
Average temp. gases escaping from boiler, °Fahr.	514	592·7	658·8	558·3	587·5	603·7	560·3
Average temp. feed water, °Fahr.	76·6	....	56·6	56·0	56·0	56·0	57·2
Pounds dry coal fired per hour	1,084	1,020	1,179·2	1183·3	1,347·8	1,183·5	1,242·2
Actual water fed per hour, pounds	6,380	6,550	7,984	7348·1	8,803·6	8,471·4	9,217
Equiv. water evap. per hour from and at 212° Fahr.	8,495	8,476·8	10,290·4	9437·2	11,321·4	10,909·5	11776·4
Pounds water per pound coal, actual	5·37	6·418	6·635	6·111	6·401	6·986	7·36
Pounds water per pound coal, actual, from and at 252° Fahr.	7·15	8·309	8·726	7·975	8·40	9·218	9·48
Thermal efficiency, based on coal	79·3	75·0	74·9	76·31	77·35	80·30	74·59
Percentage of moisture in coal during test	8·66	15·6	2·00	1·6	2·00	2·4	0·8



Sectional view of Standard Bettington Boiler, showing path of gases.

R. H. Fernalde states that an examination of the installation at the works of the agents of the Bettington boiler "gave an excellent impression of the operation of the pulverizing equipment, with its freedom from floating dust. Unfortunately, no examination of the effect of fusing of the ash could be made, as the boiler was under test and access to its interior was out of the question. The company claimed that, after years of experimental work with special fire bricks, it has developed that the method of inclosing the water tubes of the boiler practically amounts to water-cooling the brick. It is, therefore, possible to dispense with special, expensive, high-grade brick for this purpose and to use common fire-brick.

"This installation consists of a boiler of slightly over 2,600 sq. ft. of heating surface, which has an evaporative capacity of 14,000 to 22,000 pounds of water per hour. The power required for pulverizing and feeding the fuel is stated to be about 3 per cent of the boiler capacity.

"No definite information regarding depreciation and maintenance was available, but by some these items are regarded as excessive.

"The manager of a steel plant in Wales reported that he was using two of these boilers. He had installed two boilers rated to evaporate 20,000 pounds of water each per hour. He stated that he was using refuse coal containing 25 to 27 per cent ash—a mixture of colliery dust and coke dust. The boilers had been installed only about two weeks and had consequently not been thoroughly tried out. Tests of the boilers showed an efficiency of 75 per cent, and the indications were that the boilers would prove entirely successful."[1]

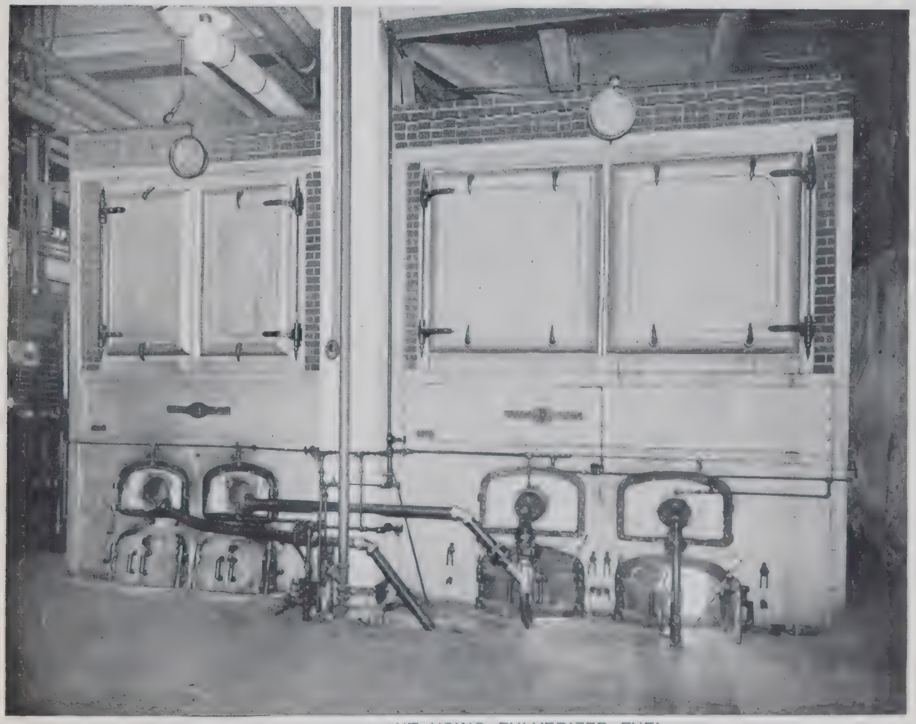
The following is the result of a comparative test[2] of a large marine-type Babcox and Wilcox boiler and a Bettington boiler of nearly the same size. The latter was the first of its type, and is no doubt capable of some improvement as the result of the experience gained. It will be seen, however, that it compared well with its older rival. The figures are as follows:

Item	Bettington tests	Babcock and Wilcox tests
Date of test	June 26, 1913	June 27, 1913
Duration of test	9·8 hours	10 hours
Gauge pressure	173·7 lbs. per sq. in.	161·9 lbs. per sq. in.
Feed temperature	65·5° Fahr	64·7° Fahr.
Steam temperature	510·3° Fahr	546° Fahr.
Water evaporated per hour	31,561 lbs.	29,370 lbs.
Coal consumed per hour (no allowance made for carbon value of ashes)	4,477 lbs.	4,183 lbs.

[1]*Notes on the Use of Low-grade Fuel in Europe.* United States Bureau of Mines. Technical Paper 123, p. 35.

[2]Paper by J. H. Dobson, South African Institution of Engineers.

DELIVERING PULVERIZED COAL BY TANK MOTOR TRUCK
The Crystal Pool, or Natatorium, Seattle, Wash.



BOILER PLANT USING PULVERIZED FUEL
500-horse-power installation in the L. C. Smith building, Seattle, Wash. Cost of installation of pulverized fuel equipment, $3,500.

Item	Bettington tests	Babcock and Wilcox tests
Pounds of water evaporated per 1 pound coal (as fired)	7·050 lbs.	7·014 lbs.
Evaporative equivalent from and at 212° Fahr. (as fired)	9·049 lbs.	9·140 lbs.
Evaporative equivalent from and at 212° Fahr. (dry)	9·464 lbs.	9·868 lbs.
Efficiency on gross calorific value	78·6 p.c.	77·4 p.c.
Percentage auxiliary power	3·8 p.c.	1·0 p.c.
Net efficiency on gross calorific value	75·6 p.c.	76·6 p.c.
Efficiency on net calorific value	81·4 p.c.	80·0 p.c.
Net efficiency on net calorific value	78·3 p.c.	79·1 p.c.

Pacific Coast Coal Company, Seattle, Wash.

This company was the pioneer in the development of the use of pulverized fuel on the Pacific coast, and, today, the industry has reached a high stage of development, particularly in connection with the use of pulverized coal for boiler plants, and for power and heating purposes.

This company owns and operates the following mines in the state of Washington: Black Diamond, Newcastle mine, and the Burnett or South Prairie mine, all of which are in the vicinity of Seattle.

The following are analyses of these coals:

Black Diamond Mine—

(As mined)

Moisture	2· 5	per cent
Volatile matter	47·25	"
Fixed carbon	46·70	"
Ash	3·55	"
Sulphur	·40	"
B.T.U.	12,651	

(Dry coal)

Volatile matter	48·46	per cent
Fixed carbon	47·89	"
Ash	3·64	"
Sulphur	·41	"
B.T.U.	12,976	

Newcastle—

(As mined)

Moisture	7·8	per cent
Volatile matter	36·55	"
Fixed carbon	29·92	"
Ash	25·73	"
Sulphur	·57	"
B.T.U.	8,842	

NEWCASTLE—*Con.*

(Dry coal)

Volatile matter	39·64	per cent
Fixed carbon	32·45	"
Ash	27·40	"
Sulphur	·62	"
B.T.U	9,540	

BURNETT—

(As mined—No. 4 vein)

Moisture	·96	per cent
Volatile matter	39·24	"
Fixed carbon	46·33	"
Ash	13·47	"
Sulphur	1·28	"
B.T.U	12,052	

(Dry coal)

Volatile matter	39·62	per cent
Fixed carbon	46·77	"
Ash	13·60	"
Sulphur	1·29	"
B.T.U	12,169	

This company owns and operates two pulverized coal plants,—one at the Newcastle mine and the other at Black Diamond mine.

Newcastle Plant—This plant has a capacity of five tons per hour, and consists of one Ruggles-Coles dryer and one 46-inch Fuller mill. The pulverized coal is used in the mine power-plant, and for shipment to Seattle.

Black Diamond Plant—This plant has a capacity of five tons per hour, and consists of one Ruggles-Coles dryer, and one Raymond mill. The pulverized coal is used in the mine power-plant and for shipment to Seattle.

The pulverized coal is shipped to Seattle in tank cars, and distributed by tank motor trucks. This company has built up a commercial business of about 30 tons per day, and the following buildings have converted their boilers from oil-burners to the use of pulverized fuel: The L. C. Smith building (42 stories), Pacific block, Broadway high school, New Richmond hotel, Seattle natatorium (Crystal Pool), and Independent laundry. The price of pulverized fuel, delivered, is $7.75 per ton, a saving over fuel oil, which formerly cost $2 per bbl. of 42 gals.

Puget Sound Traction, Light and Power Co.

In describing the results secured from the operation of a test plant for the Puget Sound Traction, Light and Power Co., Mr. Henry Hull says:

Prompted by the large amount of unmarketable fine coal, which is piled up at numerous nearby coal mines, the Puget Sound Traction, Light and Power Company has investigated the practicability of burning pulverized coal. This coal is a form of lignite particularly adapted to use in the pulverized form, owing to the high volatile constituent and the very high fusing point of the ash. To prepare this coal for burning it must first be thoroughly dried and the moisture content reduced to approximately 1 per cent before it can be properly pulverized. It must then be ground until approximately 85 per cent will pass through a 200-mesh screen and 95 per cent through a 100-mesh screen if the best results are to be obtained. It should then be fed directly to the furnace, or, if transportation or storage is necessary, it should be kept air-tight so far as possible to prevent absorption of moisture.

The coal which has been investigated by the Puget Sound Company is dried and pulverized by the Pacific Coast Coal Company at its briquetting plant, near Renton, which is equipped with a Raymond pulverizing plant. It is then loaded in a box car having a metal-lined hopper. The car is spotted at the steam plant over a chute which is connected to the car by a flexible hose. The chute feeds a small metal-housed conveyor, which elevates and dumps the coal into a bunker adjoining the power plant. From the bottom of this the fuel is fed, by means of two motor-driven screws, into a 3-inch (7·62-cm.) supply pipe, through which it is then blown to the front of the furnace. At this point the fuel is discharged into the side of an injector, consisting of a 16-inch (38·1-cm.) drum, surrounding a nozzle on the end of a 10-inch (25·4-cm.) air-supply pipe. Dampers are provided in the drum and air pipe to regulate the amount of air supplied to the combustion chamber. In starting operation the coal dust is allowed to drop on an oil flame, although any small fire built under the fuel discharge pipe would have the same effect. An extended Dutch oven, with a broad arch, is used to assist ignition, as considerable combustion space is required to secure satisfactory results, a parabolic shape being most desirable. Fire cannot travel back into the fuel supply pipe as long as the rate of air supply is greater than that of fuel propagation.

A record of a 12·8-hour test on the equipment is given herewith. The duration of the test was limited by the facilities for storage and handling of the fuel. The coal was weighed in the car as delivered to the plant and the net weight determined by a subsequent weighing of the car after unloading. The test was run until all coal was consumed. The water was measured by a Venturi water meter installed in an individual feed line to the boiler, and all instruments were checked for accuracy before starting.

During the test it was noted that the boiler could be forced to 200 per cent of rating without any apparent damage to brick setting or tubes. The stack was perfectly clear under these conditions, and there was no fusing of the ash. About one-third of the ash was found deposited in the second and third passes of the boiler, none whatever being found to have collected on the tubes.

Test of 300-Horsepower B. & W. Boiler Burning Pulverized Coal

(Coal analysis)

Moisture	5·4	Ash	10·4
Volatile	37·2	Sulphur	0·56
Fixed carbon	47	B.T.U.	11,760

(Ash analysis)

SiO^2	44	CaO	7·75
FeO	10·45	MgO	2·40
$A1^2O^3$	32·88		

(Screen Test of Coal)

Per cent of coal passing on 100 mesh	5·8
Per cent of coal passing through 100 on 200-mesh	34·6
Per cent of coal passing through 200-mesh	59·6
Duration of test (hours)	12·8
Average boiler-horsepower developed	357
Total water evaporated (lbs.)	143,231
Average temperature of feed water (deg. Fahr.)	185
Average steam pressure (lbs. gauge)	106·5
Average temperature of steam (deg. Fahr.)	399
Average flue-gas temperature (deg. Fahr.)	528
Average draft at uptake (ins. water)	0·17
Average flue-gas analysis, in per cent:	
CO^2	17
Oxygen	2
CO	0
Total coal burned (lbs.)	18,389
Actual evaporation per lb. of coal (lbs.)	7·8
Equivalent evaporation from and at 212 deg. Fahr. (lbs.)	8·6
Boiler efficiency (per cent)	71

The result of the experiment tends to refute most of the adverse criticism of this method of burning coal. There was no formation of slag in the furnace or on the tubes, there was no shower of cinders and ashes emitted from the smokestack, and there was no damage done the boiler from heavy overload under these conditions.

From the experiments in burning these various fuels it was found that —assuming pea coal at $1.60 per gross ton ($1.76 per net ton)—the prices which could be paid for other fuels on the basis of equal heating values are as follows: Pea coal on chain grates, $1.60 per gross ton, delivered; fuel oil, 56 cents per barrel, delivered, and pulverized coal, $2.20 per gross ton, delivered.

The temporary plant was designed by E. B. Powell, of the Stone and Webster Engineering Corporation, of Boston, Mass.

The Puget Sound Traction, Light and Power Company have recently installed a pulverized fuel plant and have converted all their boilers for the use of this class of fuel.

American Locomotive Company, Schenectady, N.Y.

Answering a request for information, the American Locomotive Company wrote, under date of November 7, 1917, as follows:—

"Replying to your letter of October 24, regarding the use of pulverized fuel, I take pleasure in giving you the following information:

"(*a*) The advantages of using pulverized fuel in place of coal in its natural state, fired either by hand or by stokers, are economy, regulation of the fire, and quick starting of the fires. We have been using pulverized fuel on one 300-h.p. Franklin-type boiler for about four years, and we are getting results on this boiler far superior to the results we are able to obtain on similar boilers fired with stokers. We can get higher efficiency and more overload capacity with less maintenance on this boiler than on our stoker-fired boilers. The only disadvantage we have found is the cost of drying and pulverizing the coal. This, of course, varies according to local conditions.

"(*b*) We have never used producer-gas or oil on our stationary boilers at this plant, hence cannot give you any comparative data for steam generation. In industrial furnace work, however, we have been using oil, but we are now changing as rapidly as possible our furnaces over so that pulverized coal can be used. The advantages of pulverized coal are chiefly economy and the fast heats which are obtainable. The only disadvantage is the first cost of the installation, which is somewhat higher than where oil is used. This, however, is more than offset by the saving effected by the use of coal.

"(*c*) Tests made on our pulverized fuel-fired boiler show that we can secure 70 per cent efficiency on this boiler as compared with 60 per cent efficiency on the stoker-fired boiler. Tests made on our industrial furnaces are not representative of present conditions. We are now making a series of tests, and could furnish you further information later along this line if you are interested.

"(*d*) An analysis of the coal which we used in the pulverized state is as follows:—Ash, 10%; volatile, 30%; sulphur, 2%; B.t.u., 13,900; moisture, 350; fixed carbon, 58%.

"(*e*) Coal is delivered by car over a track hopper to our milling plant; bottom-dump cars are usually obtained, and the coal flows by gravity into a crusher, where it is crushed to ¾″ cubes, whence it is delivered into a bucket elevator which carries it to an overhead bin. From this point it runs by gravity through a feeder, in order to get a uniform flow into the dryer. On leaving the dryer it is picked up by the elevator and placed in another bin, from which it flows by gravity to the pulverizer. After leaving the pulverizer, it is carried by a screw conveyor into a storage bin, from which it is delivered to the hoppers in the shops. This arrangement of the plant we have found is not ideal, and we would make some changes if we were to install a new plant. We have also installed a new system of conveying coal, which does away with the screw conveyor."

Cement Industry

Pulverized coal has been used in connection with the manufacture of cement since 1895. It is estimated that, at the present time, about 10,000,000 tons of coal is pulverized annually in the United States for use in this industry. The following letters from cement plants in Canada show the advantages of this class of fuel over the old method of coal firing:

Canada Cement Company, Limited

"We beg to acknowledge receipt of yours of the 7th inst., making enquiry in regard to the use of powdered coal in burning cement in our rotary kilns, and would give you the following answers to your questions:—

"(a) The use of powdered coal is practically the only way in which it can be used in connection with the rotary kiln (except by gas producers).

The rotary kiln has superseded the old stationary kiln, largely on account of the greatly reduced labour cost in connection with its operation. We have had no experience with stationary kilns but it is generally conceded that they are more economical in fuel consumption than the rotary kiln, but this advantage is more than offset by the very greatly increased labour cost, and the difficulty in getting as good quality of cement as from the rotary kiln.

Gas producers have been tried in several cement plants, but they have not been generally adopted, as they offer no advantage in fuel economy and give more trouble in operation.

"(b) The class of coal that we find most suitable for rotary kilns has an analysis of about as follows:

Volatile matter	35 to 40%
Fixed carbon	50 to 60%
Ash	less than 10%
Sulphur	low as possible

"(c) The quantity of coal required per barrel of cement varies with the material used, the amount of moisture in it, and the length of the kiln used. In the dry process, that is, where the raw materials are put in the kiln in a dry state, a consumption of about 100 lbs. per barrel is about the average in present day practice. It is somewhat less in long kilns and considerably more in short kilns.

"For comparison between rotary and stationary kiln *see* answer to question 'a.'

"(d) We have no photographs available of our coal plants, and would say that they vary considerably. In general, the process is as follows:

"The coal must be first crushed, if it is received in the form of lump or run-of-mine, then dried—which is usually done in rotary dryers—then pulverized, for which a number of machines are on the market. The coal is pulverized to a fineness of about 95% through a No. 100-mesh screen (10,000 meshes to the square inch) and is then blown into the kilns through a pipe leading in to the front.

"You will find cuts and general description of the feeding apparatus on pages 487 to 490 of *Eckle's Cements, Limes and Plasters*, also on pages 220 to 222 of *West's Manufacture of Portland Cement*. These books also give descriptions and cuts of the drying and grinding machinery commonly used for coal.

"We trust that the above may answer your purposes. Yours truly,

(Signed) "A. C. Tapp, Assistant General Manager.

"Montreal, May 17, 1917."

HANOVER PORTLAND CEMENT COMPANY, LIMITED, HANOVER, ONT.

"We have your letter of the 8th instant with reference to the use of pulverized coal as fuel. We will endeavour to answer your questions to the best of our ability.

"(*a*) The disadvantages in using pulverized coal for fuel we find to be as follows: First, the cost of drying and grinding; this, in our plant, is estimated to cost about 25 cents per ton. Second, the liability of the pulverized fuel to ignite spontaneously. As a rule, we do not have any trouble from this source, but certain precautions have to be taken to obviate this danger. The advantages are: First, absolute control of temperature; second, no clinkers to remove, absence of smoke, and the utilization of practically all the heat units in the coal.

"(*b*) For cement burning, we have tried four different grades of slack, namely, Youghiogheny, West Virginia, Hocking Valley and anthracite screenings. We find the first two, or, in fact, any good gas coal, will give good results. The Hocking Valley coal, which is more of a lignite in character, worked fairly well, but the differences in price in normal times would not warrant its use. The anthracite screenings proved a failure with us.

"(*c*) We have no data on the comparison of the amount of pulverized fuel used in cement burning as compared with the ordinary variety, as in rotary kiln work we have always had to pulverize our coal. At this plant, burning a slurry containing 55 per cent of water, we use about 175 pounds of coal per barrel of 350 pounds.

"(*d*) The flow-sheet at our plant is as follows: Coal is furnished in hopper-bottom cars of 45 to 65 tons capacity, and unloaded by means of track hopper and elevator to either storage pile or bins. From the bin it is elevated and passed through rotary dryer 4 feet diameter by 40 feet long, fired with slack coal on boiler grates. From the dryer it is again elevated, and passed through Bonnot pulverizer, grinding so that 95 per cent passes 100-mesh sieve, from which it is again elevated and transferred by screw-conveyor to storage tanks in front of the kilns. From these it is fed into the kilns by means of a small screw-conveyor in the bottom of the tank, the speed of which can be regulated to feed any amount of coal necessary.

"The coal at the end of the screw is picked up by an air blast from a fan 30 inches in diameter, running 2,400, and forced through 5-inch galvanized pipes into the kiln.

(Signed) "S. R. FROST, Supt.

"Hanover, Ont., May, 10, 1917."

NATIONAL PORTLAND CEMENT CO., LIMITED, DURHAM, ONT.

"We are in receipt of your letter of May 8th, asking for information respecting the use of pulverized fuel in connection with the manufacture of cement, and we give you the following information to your questions:—

"(*a*) The use of pulverized coal in rotary kilns has supplanted all other methods of burning cement on account of temperature and output being under control.

"(*b*) Bituminous coal only used. The higher the volatile matter and the lower the ash the better.

"(*c*) From 50 per cent to 100 per cent more coal used in rotary kilns compared with upright continuous kilns, but saving in labour more than compensates for this.

"(*d*) Slack coal unloaded direct from cars to rotary dryers and ground in Fuller Lehigh mills—95 per cent passing a 100-mesh sieve.

"National Portland Cement Company, Ltd.,

(Signed) "R. H. MCWILLIAMS, Manager.

"Durham, Ont., May 10, 1917."

Metallurgical Industries

The application of pulverized fuel has been developed to a very considerable extent in connection with various kinds of metallurgical work.

In the iron and steel industry some 2,000,000 tons is used annually in various types of furnaces, such as open hearth, heating, puddling, soaking pits, continuous heating, reheating, annealing, forging furnaces, and furnaces of practically every description where heat is required.

It is very evident that the future possibilities of the application of pulverized coal are now being recognized by the large steel companies as a subject worthy of their careful investigation. The Manitoba Bridge Company is installing a pulverized coal plant in connection with its open hearth steel furnace at Selkirk, Man. The Armstrong-Whitworth Company, of Longueuil, Que., has installed a plant for its heating furnaces.

A great development has taken place in the application of this class of fuel in connection with the copper industry—ore-roasting furnaces, reverberatory and copper-melting furnaces of all types. Between 1,000,000 and 2,000,000 tons of pulverized coal is used in this industry alone each year.

International Nickel Co., Copper Cliff, Ont.

When the reverberatory plant at Copper Cliff was built in 1911, the furnaces were designed to be fired with pulverized coal, and the necessary machinery for preparing the coal was installed.

The original furnaces were put in commission in December, 1911, and almost from the first the new method of firing proved a success. There was some trouble from ash accumulating at the throat, but, when the furnaces had been brought up to a good smelting rate, this ceased to cause any serious inconvenience. Some ash always tends to deposit at this point, and it should be removed each day. It is in a semi-molten state when deposited, and tends to build up rapidly if not removed at regular intervals. Pulverized coal has been used in this plant ever since, and there has been no reason to doubt the wisdom of adopting it. In the last few years the use of pulverized coal in reverberatory work has almost entirely supplanted grate-firing, and in a number of instances has even replaced oil-firing.

As the men operating the furnaces became more familiar with the new method, certain alterations suggested themselves. These have been incorporated at various times when a furnace was under repair. At present, excellent work is being done, far surpassing anything ever accomplished under the earlier standard method of grate-firing.

There were originally two reverberatory furnaces at Copper Cliff, but only one is operated now, the other having been dismantled. The complete reverberatory plant includes the following departments: Ball mills, storage bins, wedge furnaces, coal grinding, reverberatory furnace proper.

There are four ball mills, each crushing about 125 tons of ore per day, to a size suitable for calcining in the four wedge furnaces. The storage bins hold about 1,000 tons of coal and 3,000 tons of the crushed fines, besides small quantities of other materials which go to make up the charge to the reverberatory. The bulk of the charge, however, is the calcined ore from the wedge furnaces. This amounts to about 80 per cent or 90 per cent of the total charge. The reverberatory furnace is 112 ft. long and 19 ft. wide. Furnaces of approximately these dimensions are in common use at most large copper smelters. A few of a larger size have been built, however.

The coal used is bituminous slack, having about the following analysis:—Volatile, 35 per cent; fixed carbon, 52 per cent; ash, 13 per cent; sulphur, 1·50 per cent.

The moisture varies with the season, ranging from abour 5 per cent to 9 per cent. For the month of April it was about 8 per cent. The coal is received at the storage bins in side-dump railway cars, which discharge directly into the bins. From the bins the coal is drawn on to

either of two belts which run under and parallel with the bins. These belts convey the coal to Jeffrey coal crackers, which reduce any lumps to a maximum of 1″. A belt at right angles to the former two takes the discharge from the crushers and conveys it to the grinder building proper. Here it is first passed through a Ruggles-Cole rotary dryer, 33 ft. long. There are two of these, but unless the coal is unusually wet it is only necessary to operate one. It is very important to get the coal as dry as possible, but it has not been found practical to reduce the moisture much below 1·5 per cent.

From the dryer the coal drops into a screw conveyor, and thence to an elevator and to storage bins which are behind and above three Raymond, 4-roller pulverizers. Each pulverizer is driven by a 75 H.P. motor, which also operates the fan which draws the coal dust from the pulverizer when fine enough, and deposits it in a collector at the top of the building. From the collector the fine coal is conveyed by a spiral conveyor to a storage bin, behind the reverberatory furnace, having a capacity of about 60 tons.

The coal is fed from the storage bin by means of five short screw conveyors, spaced about 3 ft. apart, which drop it in front of an air blast, by which it is blown through five 5-inch pipes, projecting through the bridge wall of the furnace. The blast is supplied at about 5 or 6 ozs. pressure by two No. 8 Sturtevant blowers. This blast furnishes only part of the air required for combustion. The balance is drawn in by natural draft through openings in the bridge wall. The draft is controlled by a damper in the flue a short distance from the furnace. It is usually equivalent to about ¾″ to 1″ of water.

By means of the damper and the feed screws, which have a variable speed from 15 r.p.m. to 40 r.p.m., it is possible to burn any amount of coal or obtain any length of flame required for the proper operating of the furnace. If it is desired to burn more coal and keep the flame the same length the feed screws are speeded up and the damper opened somewhat. If a longer flame is required, the damper is closed. At full capacity about 100 tons of coal can be burned in 24 hours.

At the present time, about 70 tons per day is being burned and between 450 and 500 tons of charge is being smelted. For the month of April, 1919, 2,094 tons coal was burned and 13,547 tons solid charge was smelted. This works out to about 6·5 tons charge smelted for each ton coal burned. In the old grate-fired type of furnace about 4 to 4·5 tons charge to 1 of coal was the best that could be done, and it was only after a long period of evolution and in the best-managed plants that this was accomplished. For a day or two at a time the Copper Cliff plant frequently smelts over 7 tons charge per ton of coal.

Burning the coal in the pulverized form permits the use of a much poorer quality than could be successfully used on grates. Coal containing as high as 17 per cent ash has frequently been used at Copper Cliff, without causing any particular trouble. At Anaconda, coal with 22 per cent ash

has been used and L. V. Bender states that it was easier to keep the flues clean when using this coal than when using another grade containing only 9 per cent ash. Slack coal has proved perfectly satisfactory, and has the advantage in cost over lump.

The size to which the coal is reduced is of the utmost importance, At least 95 per cent should be finer than 100 mesh, and from 75 per cent to 80 per cent finer than 200 mesh. Given coal of this degree of fineness and a proper mixture with air, the combustion is rapid and complete. The volatile matter is also of some importance and, though coal containing as little as 22 per cent has been used in cement work, it would probably be inadvisable to go below 33 per cent volatile in reverberatory furnace work.

The working temperature of the furnace is about 2,800° to 2,900° Fahr. at the hottest part, gradually diminishing to about 2,000° Fahr. at the flue end.

A higher temperature could readily be obtained but would cause undue wear on the furnace roof. The temperature is at all times under perfect control, through the amount of coal burned and the amount of ore charged.

The use of pulverized coal has caused considerable modification in the method of feeding the ore. When grate-firing was practised, it was customary to drop a large amount at stated intervals through holes in the roof near the firing end. The present method is to introduce the entire charge along the sides of the furnace. A longitudinal hopper runs along either side of the furnace a short distance above the roof. From this hopper, six-inch pipes, spaced about 2 ft. apart, run to holes in the roof close to the side walls. The hopper is kept full of ore, which runs down the pipes and forms a pile against the side wall of the furnace. As the charge in the furnace smelts and runs away, more ore at once comes down from the hopper. Charging is thus continuous, and very little of the brick work of the furnace, except the roof, is exposed to the flame. This makes the life of the side walls practically unlimited, the roof being the only part requiring regular repairs. Portions of the roof have to be replaced every six or eight months, and a complete new roof is put on about every two years.

The chief advantages of coal-dust-firing over grate-firing were enumerated by Mr. Sorensen, in an article in the *Engineering and Mining Journal*, February 10, 1906, as follows:—

(1) The action is continuous; there are no stops for grating.
(2) The heat generated is uniform and steady.
(3) Combustion is complete at all times.
(4) Combustion is rapid and concentrated and therefore productive of high temperature.
(5) Combustion takes place where the heat is most wanted.

The following letters give in brief form the results obtained in certain metallurgical plants in the United States:

Milton Manufacturing Company, Milton, Pa.

"Replying to your communication of the 26th ultimo, regarding pulverized fuel for steam raising in stationary boiler plants and locomotives, we have had in operation a pulverizing plant for practically ten years. We use it in heating furnaces, also in our puddle furnaces.

"We have never experimented on its use in firing battery boilers. We have found from observation that this system saves from 30 to 35 per cent of fuel consumption and gives us approximately 20 per cent greater output, due to the fact that the cleaning of the grates, which is necessary in the hand-firing method, is not necessary when this method is used. We use a high volatile coal with low ash.

"We trust this information will fulfill your desires.

"Milton, Pa., Oct. 1, 1917."

Fort Wayne Rolling Mill Corporation, Fort Wayne, Ind.

"We are in receipt of your esteemed favour of September 26, and advise you as follows:

"(*a*) The advantages in the use of pulverized coal over direct method of firing consists—

1st. In saving of fuel.

2nd. Saving of cost in handling coal and delivering it to furnaces or boilers.

3rd. Saving of handling of ashes. There is much nearer perfect combustion of the coal in pulverized-fired than in hand-fired furnaces, consequently less ashes to handle.

"(*b*) We have never burned fuel-oil and have no information on the comparative advantages or disadvantages of pulverized coal over fuel-oil.

"We have rather an antiquated producer-gas plant and are still burning producer-gas at some of our heating furnaces. The advantage of pulverized coal over producer-gas is principally due to more economical handling of both the coal and the ashes in the pulverizing plant. We believe that the heat values are approximately the same with either method of combustion.

"(*c*) For several years we used direct firing of coal at our puddle furnaces. In 1914 the consumption of coal per ton of finished muck and scrap bar on hand-fired furnaces was 1,796 pounds of coal. In 1916, on the same furnaces, fired with pulverized coal, the consumption of coal per finished ton of muck and scrap bar was 1,034 pounds. We have to advise you, however, that the real difference was not as great as these figures would seem to indicate. In 1914 we were operating very irregularly and fuel consumption under these conditions was naturally high. In 1916 we were operating at pretty nearly full capacity during the entire year, and naturally secured the best results from fuel consumption.

"Another factor that should be carefully considered is that we use waste heat boilers on all of our puddle mill furnaces, and our experience with pulverized coal furnaces is that the steaming capacity of our boilers is reduced very materially by the use of pulverized coal.

"Before installing pulverized coal our puddle mill furnaces were all heated with direct hand-fired furnaces; also our 8-inch finishing mill, and all of these furnaces were equipped with waste heat boilers. Our 9-inch and 18-inch finishing mills were served with producer-gas and were not equipped with waste heat boilers. In order to overcome the deficiency of steam caused by installing pulverized coal, we were compelled to install pulverized coal at our 18-inch bar mill and equip the two furnaces at this mill with waste heat boilers. Ultimately, we expect to equip our entire mill with pulverized coal, but can not afford to shut down our mills in order to make the installation at this time.

"(*d*) Analysis of the fuels used at our plant: We find that the best results are obtained by using the best coal, and that it is impossible to get anything like satisfactory results with poor coal. We find Indiana and Illinois bituminous coal very unsatisfactory; some grades of Ohio bituminous coal are fairly satisfactory, but we get the best results from eastern Kentucky and northern Tennessee coal. Our experience justifies us in the statement that any coal running above 33 per cent in volatile combustibles and not under 13,000 B.T.U. will work satisfactorily, provided it is not too high in moisture. If the moisture exceeds six or seven per cent, we experience considerable difficulty in getting it dry enough to pulverize properly. We give you below an analysis of coal coming from Harlan county, Ky., which we have found the most satisfactory of any coal that we have used in our plant:—Moisture, 3·96 per cent; volatile combustible, 37·60 per cent; fixed carbon, 55·30 per cent; sulphur, 0·75 per cent; ash, 5·63 per cent; B.T.U., 14,047.

"(*e*) A brief description of our plant is as follows: The coal is delivered to us from the mines in hopper or drop-bottom cars, is carried to an elevated track, where it is dumped automatically into a hopper, from which it is fed automatically through coal crusher and carried by elevating machinery to the top of our coal-milling plant. From this point it can be taken either into storage or directly into our milling system by means of switches into the conveyor line. If taken into storage it is carried automatically by helicoid conveyor which runs the entire length of our storage warehouse back into the milling system. If taken direct from the cars into the milling system, it goes into a bin, from which it is fed automatically into a Coles and Ruggles dryer and is then loaded automatically into another bin, from which it is fed automatically into two Raymond pulverizers. When pulverized fine enough for use it is carried by air exhaust to the cyclone collector on to the top of a building, and from thence it is precipitated into a storage bin. From this bin it is carried automatically by helicoid conveyors to the various furnaces.

"Installed in the main line of this conveyor system is an automatic scale, which weighs and registers the tonnage of coal passing through the conveyor. At each of the scrap or puddling furnaces there is a 3-ton bin, from which the coal is fed automatically by proper conveyor into the furnaces under air pressure. The auxiliary air pre-heated is also delivered to the mouth of the furnaces at the same time. Furnaces are equipped with combustion chamber, which is separated by a bridge from the chamber in which the metal is contained. Initial combustion takes place in the combustion chamber. The heat passes over the metal and from thence through waste heat boilers into the stack.

"Our installation was made by the Quigley Furnace and Foundry Co. (now the Metals Production Equipment Co.), of Springfield, Mass.

"The controllers used at the mouth of the furnaces are of the Cullaney type, but we have since displaced one of these controllers with a controller of our own manufacture, which we have patented, and which is giving us very much better results than the Cullaney controller. We expect to equip all of our furnaces as rapidly as possible with these new controllers unless we find something better that is made by someone else.

"Fort Wayne, Ind., October 11, 1917."

Bethlehem Steel Company

(Steelton Plant, Steelton, Pa.)

"Replying to inquiry in your letter of September 26, referred to further in your letter of the 2nd inst., addressed to Mr. Quincy Bent, General Manager of the Bethlehem Steel Company, Steelton plant, I am sending you with this, a copy of some general information about our experience in burning pulverized coal, which, I trust, will be of interest to you in this connection. In addition, I beg to submit the following in answer to the list of questions you submitted:—

"(*a*) The advantages or disadvantages of pulverized fuel over direct method of firing coal depend largely on the character of the service. In general, we believe that for boiler firing, fully as good an efficiency and much lower cost can be obtained by direct firing. In metallurgical furnaces, direct firing is not always feasible, and, in these cases, pulverized fuel has many of the advantages of fuel-oil or gas, such as a higher temperature flame and a more perfect control of the fire. Its disadvantages are the expense of pulverizing the coal and the trouble from the fine ash in the furnaces and flues, which, however, are not serious for many classes of service.

"(*b*) Pulverized coal has the advantage over the use of producer-gas of giving a higher temperature flame than can be obtained with the gas without the use of regenerators. The efficiency with pulverized coal will also generally be higher than can be obtained by the use of the same coal in producers, unless the heat developed in the producer can be utilized directly in the furnaces. We do not believe that producer-gas can be used for boiler firing to advantage. As compared with gas having a higher thermal value than producer-gas or with fuel-oil, the question of the advisability of using pulverized coal will depend almost entirely on the cost, taking into account the expense of pulverizing the coal. In this case, however, the disadvantage from the fine ash in certain classes of work might make it advisable to use gas or oil, even though the relative costs were somewhat higher.

"(*c*) The general report referred to in the first paragraph of this letter furnishes all of the information about tests of use of pulverized coal which we have available.

"(*d*) A typical analysis of the coal used in our pulverizing coal equipment is presented in the aforementioned report. In general, the fuels used at the Steelton plant of the Bethlehem Steel Company comprise practically everything that is available in the Eastern Pennsylvania markets.

"(*e*) The pulverized coal equipment on which we base this report consists of pulverizers made by the Bonnot Company, Canton, Ohio, combined with the Holbeck system of air distribution to the burners made

by the same concern, from whom you can probably obtain a complete description of the plant as it was installed for us. The greater part of the coal is burned in continuous furnaces for heating steel blooms and billets for rolling. For this service the results have been generally highly satisfactory and the efficiency has been good. A part of the coal has been used in hearth furnaces for heating large blooms and ingots for forging. In this service the results have not been as satisfactory as with direct firing by the use of underfeed stokers of the Jones type. Some of the difficulties with the pulverized coal in this work are outlined in the attached general report.

"STEELTON, PA., October 6, 1917."

General Report of Use of Pulverized Coal in Heating Furnaces, Bethlehem Steel Company, Steelton Plant

"(*a*) Coal analysis—Volatile, 32·50 per cent; fixed carbon, 56·10 per cent; ash, 11·40 per cent; sulphur, 0·75 per cent.

"(*b*) It requires 15·41 horse-power-hours to pulverize a gross ton of coal. Power used in the plant by the various motors is as follows:

Motor duty	Rated horse-power	Actual horse-power used
Motor delivering coal to raw coal bin	8	2·01
Motor feeding coal from raw coal bin to kiln	5	1·34
Motor driving kiln	10	6·94
Motor driving pulverizer	35	29·62
Motor delivering pulverized coal to storage bin	10	8·99
Motor delivering coal from storage bin to conveying fans	5	2·01
Motor driving conveying fan	35	26·55

"(*c*) In answering queries in third paragraph, we are using as a basis for the information our 14-inch and 16-inch mill continuous heating furnace. The fan or blower discharges the mixture through a 12-inch pipe, and is driven by a constant speed motor which is rated at 35 horse-power and has an actual consumption of 26·55 horse-power. This fan discharges 3,826 cubic feet of mixture, containing 29·68 pounds of coal, per minute against 10·16-inch water pressure; 19·43 per cent of this volume of mixture is returned, so that the actual coal consumption is 23·91 pounds per minute in 3,082 cubic feet of air. Consumption of coal per hour is 1,435 pounds. The furnace was built for pulverized coal, and other fuel has never been tried in it. The weight of steel heated per ton of coal is not available, but on our 26-inch mill continuous heating furnace, the one which you inspected when at Steelton, it requires between 100 and 125 pounds of coal per ton when cold steel is charged.

"(*d*) The repairs on pulverized coal-fired furnaces are more frequent than on stoker-fired furnaces. This is due to the fact that the gases, which carry more ash and travel at a higher velocity, cut out the brickwork very fast, unless the burners are perfectly aligned, a condition which it seems almost impossible to obtain.

"(*e*) Pulverized coal as a fuel works very satisfactorily on the continuous heating furnaces in which blooms and billets are heated, and, with the exception of some trouble which has been experienced in getting a constant supply of coal to the conveying fans, the system is a success.

"As to labour saving, coal saving and increase of production, it is impossible to give any information, as these continuous heating furnaces were designed and built for pulverized fuel and never worked under any other conditions.

"The forge furnaces, which are equipped for burning pulverized coal, have not been as much of a success as the continuous heating furnaces. The main objection to this fuel is that the gases pass through the furnace at such a high velocity that a good soaking heat is not obtained, unless the damper is down, in which case the gases are driven out into the mill, and, since much ash is carried with them, the mill cranes and presses are showing signs of wear. The mill men object to this dust, and probably do not give the furnace the attention it should have. It is said by the heater and forge men that, when large ingots, say 4 or 5 feet in diameter, are put in one of these furnaces, they must be turned more frequently than in stoker-fired furnaces, in order to get them uniformly heated, and that there is a tendency for the gases to cut the ingot on the top side. The ash which does not go out the stack is dropped in the flues and stack of both the forge and continuous heating furnaces and must be frequently removed.

"The irregularity of feed has been due to improperly designed hopper on pulverized coal storage bin. The opening from the bin to the worm conveyor box was only about 12 inches wide, and the coal would frequently arch and cut off the supply to the furnaces. The furnace heater would speed up the worm feed drive to get more coal, and when the arch would break the coal would flow out along the worm feed down into the conveying fan and the furnaces would get a mixture too rich in coal. The heater would then cut the feed until it was down to normal. In this way, it was impossible to have uniform furnace conditions. This hopper has been made larger and I understand much of this trouble has been eliminated."

National Malleable Castings Company

(Sharon Works, Sharon, Pa.)

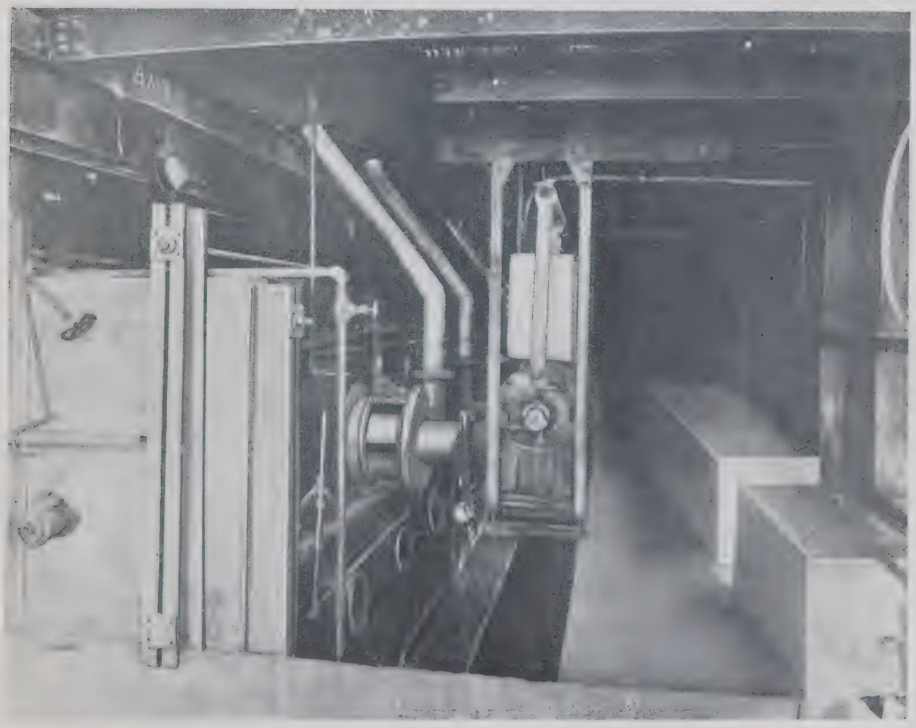
"In reply to your letter of September 26 asking for information respecting the use of pulverized coal for steam raising in stationary boilers and locomotives, also in connection with metallurgical work.

"We do not have data of our own knowledge bearing on the application of such fuel to stationary boilers or locomotives, as we have not deemed it wise to attempt experiments and make such application under conditions existing at our plant.

"Our efforts have been entirely along the metallurgical line. The application of pulverized fuel to basic open hearth furnaces was original at this plant, and we have so operated successfully and continuously for the past five years. Pulverized coal displaced the use of fuel-oil without any sacrifice of tonnage or quality of the product in any way, and with very gratifying economies.

"We designed our installation and equipment ourselves to meet the conditions existing at this plant, and I feel loath to offer data that might be misleading under other conditions, especially as the application has been tried by a number of steel companies with more or less indifferent success.

BRITISH COLUMBIA SUGAR REFINING CO., VANCOUVER, B.C.
Pulverized coal equipment, on Badenhausen boilers, installed by Fuller Engineering Company.



BRITISH COLUMBIA SUGAR REFINING CO., VANCOUVER, B.C.
Boiler room, showing pulverized fuel supply system.

"I suggest that you communicate with the Powdered Coal Engineering and Equipment Co., 2401 Washington Boulevard, Chicago, Ill. These people operate an extensive experimental department, and, I understand, have compiled quite complete data for the application of such fuel to a wide variety of uses.

"SHARON, PA., October 10, 1917."

SCRANTON BOLT AND NUT COMPANY, SCRANTON, PA.

"We are in receipt of yours of the 26th instant and note your inquiry regarding the use of pulverized fuel for steam raising in stationary boiler plants and locomotives, and as a fuel in connection with metallurgical work. We are pleased, indeed, to give you any information on this subject that we have at our disposal.

"As for general data, we are not in position at this time to give you intelligently such information as would be of any great assistance to you. We can say, however, that we have been using a system of pulverized coal in our puddle furnaces, scrapping furnaces, and re-heating furnaces in our finishing mills for several years, but, at this time, we are quite sure that the saving in dollars and cents throughout, for the size of the plant that we operate, is not as economical as we had hoped for, for the simple reason that labour is so extremely high that it has been somewhat of a disappointment in this direction. On the other hand, from a point of uninterrupted service, it is very satisfactory, and we mean by this that, by the old method of hand-firing, there is a very decided loss at the end of each turn in a rolling mill in the time consumed for cleaning grates and getting the furnaces back ready for operation again. This occurs, as you may well know, twice in twenty-four hours. With the pulverized coal, it is a constant operation from the time we start up on Monday morning until the end of the week's work on Saturday night.

"To answer questions A, B and C intelligently, we would refer you to the Locomotive Pulverized Fuel Company, 30 Church Street, New York City, Mr. John E. Muhlfeld, President, who is an American engineer of high standing; he has given this subject very exhaustive investigation and has written quite considerable about it. He also has tables showing the results obtained in locomotive work, and, by the way, in this particular line he is without doubt the most advanced of any engineer on this subject, as well as for direct firing in stationary boilers.

"Mr. Muhlfeld has equipped several plants for the Delaware and Hudson Company, both around their mines for steaming purposes and also several of their main line locomotives which are constantly in active service. You may probably know of his work.

"The analysis of coal that we are using here in our pulverized fuel plant is about as follows:—Volatile, about 30 per cent; sulphur, less than 2 per cent; ash, not over 8 to 9 per cent or less; moisture, from 5 to 6 per cent; B.T.U., 13,000 to 14,000 per cent.

"Of course, one of the important requirements for this work is a coal of high volatile, low moisture and low ash. On the other hand, Mr. Muhlfeld has demonstrated very clearly his ability to pulverize coal of quite low grade and burn it very successfully.

"To answer your question *e*, our plant has the usual grinding mill to break down the run-of-mine coal, and then the ordinary Ruggles coal dryer and a tube mill such as they use around the ordinary cement plants. We

are, however, installing at present a Fuller mill, as we believe, after several years of service, that the Fuller type of mill is far superior to the tube mill for this purpose, and we believe that it is the best type on the market to-day. This decision we have arrived at after careful investigation.

"SCRANTON, PA., September 29, 1917."

REPORT ON USE OF PULVERIZED COAL AT SHARON OPEN HEARTH PLANT OF THE CARNEGIE STEEL COMPANY, SHARON, PA.

"In reply to the request for information in regard to use of pulverized coal as fuel, this fuel has been used at the Sharon plant for firing open hearth furnaces for the past two and one-half years, with fair results; however, it is still in the experimental stage in so far as its most salient disadvantage, namely, the clogging of regenerative chambers and flues with ash, is concerned.

"To answer, so far as possible, the questions in the order in which they are put:

"(*a*) The advantages of pulverized coal over the direct firing of coal are:

(1) Greater ease in handling and uniformity of feeding.

(2) Greater nicety of thermal control with consequent economy of heat and increased efficiency of operation. Its only disadvantages in this case, so far as known, would be the clogging of flues and stack with ash.

"(*b*) The advantages of pulverized coal over producer-gas or oil are:

(1) Greater economy in fuel and labour cost.

(2) In the case of producer-gas, greater nicety of control. Its disadvantage in this case is the excessive clogging of regenerative chambers referred to above.

"(*c*) The results of test made at the Sharon plant in conjunction with the results now being obtained with this fuel, point to the following conclusions:

"The best practice to be expected from pulverized coal as a fuel for open hearth furnaces is about 500 pounds of coal per ton of steel produced. Steel produced per hour, is as much as with other standard fuels. Life of furnace of the type used at Sharon, which, in a word, is but a brick shell above the charging floor, about 125 heats. The best practice will be obtained from the use of high draught, an adequate regenerative system, and pre-heated impulse and suspension air. A compromise between thermal efficiency and operating efficiency must always be made at this point until such a time as the clogging difficulty before mentioned is eliminated. Experience had led to the belief that the best results can be obtained only from a burner so designed as to thoroughly intermix the coal with pre-heated air so that combustion may take place energetically throughout the whole mass at the moment of entering the furnace or fire box. The liability of passing unburned coal through the combustion chamber is thus eliminated. This being directly in line with the best practice in burning any high speed fuel for any purpose whatsoever, needs no elaboration.

"(*d*) The analysis of the coal used at Sharon plant is normally 0·80 per cent to 1·25 per cent sulphur and between 5·5 per cent and 9·0 per cent ash. Volatile matter between 30 per cent and 35 per cent.

"(*e*) The equipment of Sharon consists of :—1 trestle bin, wet coal storage; 1 coal crusher, 20 tons per hour capacity, 20-h.p. motor, run-of-mine coal down to 2-inch ring; 1 18-inch belt conveyor to dryer, 25-h.p. motor; 1 Ruggles-Cole Engine Company coal dryer, 12 tons per hour, capacity for moisture from 10 per cent to less than 1 per cent, belt conveyor and dryer driven from same motor; 1 bucket elevator, 12 tons capacity, to elevate dried coal to storage bin, 7½-h.p. motor; 1 dry coal bin, 25 tons capacity; 1 Raymond Bros. impact coal pulverizer, 3 tons per hour, capacity, 85 per cent coal through a 200-mesh sieve, 100-h.p. motor; 1 exhauster (fan) for pulverizer connected to same motor; 340 feet 12-inch screw conveyor, 2,500 pounds per hour, ½ full, 10-h.p. motor; 6 fine coal storage bins over furnaces, 9 tons capacity; 6 4-inch screw conveyors 3 feet long, 2½-h.p. motors (available speed); 6 burners, Works' design; 1 General Electric Company motor-driven centrifugal compressor (fan), 3,200 cubic feet air per minute, 16-ounce pressure, 20-h.p. d.c. motor; 1 Ingersoll-Rand compressor, Imperial type 10—14 x 16 x 12 x 16 and 22—16 x 19 x 16 max. rev. 170 per minute, 888 cubic feet air per minute.

"There is under consideration at the present time, the use of the static head of compressed air to supplant the 12-inch screw conveyor, as the coal in the pulverized state is quite mobile and may be considered a liquid that can be conveyed in pipes. Volume (fan) air at 16-ounce pressure is used to intermix with the coal and a jet of compressed air at 80 pounds pressure to give the necessary impulse for introducing coal to furnace through the burner. At this point will say that while there are many systems for regulating pulverized coal, there seems to be little, if any, question as to the superiority of the variable speed screw for this purpose.

"It may be noted that the answers to the preceding questions are in connection with the use of pulverized coal in open hearth furnaces, as no experience has been had in other lines with the use of this fuel at Sharon.

"SHARON WORKS, CARNEGIE STEEL CO., November 9, 1917."

Pulverized Coal for Power Purposes

BRITISH COLUMBIA SUGAR REFINING CO., LTD., VANCOUVER

Replying to a request for information, Mr. Blythe D. Rogers, President of the British Columbia Sugar Refining Co., Ltd., of Vancouver, B.C., writes as follows, under date of May 16, 1919:

"I have your letter of the 9th instant, relative to our pulverized coal plant. The following information in connection therewith may be of interest to you:

"We require sufficient fuel to maintain 2,500 boiler horse-power at about 175 per cent rating, or something over 4,000 actual horse-power. The coal used is an unwashed slack coal, containing about 33 per cent ash, and having a calorific value of about 9,300 B.t.u. For the specified horse-power, we require to pulverize about 125 tons of coal per day, spread

over a period of twenty-four hours. For this purpose we have installed a dryer, heated by means of pulverized coal, and three Fuller mills, each capable of pulverizing from five to seven tons per hour. Additional equipment consists of a magnetic pulley for separating iron particles, nails, bolts, etc. from the coal, a crusher for breaking up large lumps and the necessary bins, conveyors, etc. The whole plant requires a separate building abour 120 by 40 feet, and 40 feet high.

"In the boiler room the coal is fed by screw-feed mechanism to the furnace, where it is caught up by a current of air and blown into the furnace. Little alteration had to be made to the return-tubular boilers on account of their large combustion chamber, but in both sets of water-tube boilers (Badenhausen and Babcock & Wilcox) Dutch ovens had to be built, as pulverized coal requires a very much larger furnace than oil producing equal horse-power.

"As far as we have gone with the experiments to date, the installation has proved very satisfactory from an economical standpoint. At 160 per cent of rating the combined boiler and furnace efficiency is 76 per cent under test condition.

"The drawbacks not yet overcome consist mostly of trouble with ash, which is natural in a coal of such high ash percentage. Tubes in return-tubular boilers plug solid with ash in a very short time. Beside this, large quantities of dust are thrown out into the atmosphere from the stacks, which constitutes a very serious difficulty; this we are grappling with at present. I believe that, with this problem satisfactorily solved, the installation of pulverized coal will be shown to be an unqualified success."

Excellent Results with Pulverized Coal at Milwaukee, Wis.*

On 468-hp. water-tube boiler gross efficiency of 85·22 per cent and net efficiency of 81 per cent were obtained. No slag or ash troubles. Advantages are ease of control, ability to take overload quickly, uniform efficiency, ideal banking conditions, and low draft requirements.

In its constant endeavour to improve boiler-room efficiency the Milwaukee Electric Railway and Light Co. has been investigating recently the possibilities of pulverized fuel. The experimental work was conducted in the Oneida Street plant, which is equipped with 500-hp. Edge Moor water-tube boilers and cross-compound vertical engine units. During the heating season the station is operated noncondensing to supply exhaust steam to the central district heating system operated by the company. During the early part of this year the necessary equipment for preparing and feeding the coal was installed and one boiler was equipped to burn pulverized fuel. Early in May the boiler was placed in service, and, until August, when the installation was finally proved successful, numerous changes were made to eliminate undesirable conditions encountered during the preliminary operation.

*Powers, Oct. 15, 1918, p. 556.

In a room near the plant, coal bunkers and drying and pulverizing equipment were installed, consisting of an indirect-fired dryer having a capacity of 15 tons per hour and two pulverizers, one rated at four tons and the other at eight tons per hour. This equipment was intended for an installation of five boilers. The other four are to be equipped with burners and feeders in the near future. From one of the coal bunkers the fuel as delivered to the plant was carried to the dryer supply bin by a screw conveyor and bucket elevator. From the bin coal was drawn into the drying cylinder by another screw conveyor, passing through the dryer by gravity and being discharged into an elevator carrying the dry fuel to the pulverizer supply bin. In the dryer, the moisture is reduced from 11 to 1 per cent at the rate of about 10 tons per hour. Between the dryer and the pulverizer supply bin the fuel is run over a magnetic separator pulley which removes such iron and steel as has been carried that far. From the supply bin last mentioned the fuel is fed to the pulverizer through a small screw conveyor located on top of the mill and driven from the mill shaft by means of a small belt whose speed can be varied through a cone-pulley arrangement. This allows for variable feeder speed, depending on the kind of coal being powdered.

By another screw conveyor the pulverized fuel is carried on to a storage bin located in front of the boilers. The pulverizing equipment and the various conveyors are motor-driven and so arranged that only such machinery as is in use will be operating.

To fire the fuel into the furnace the equipment consists of a blower and two screws, driven by variable-speed motors. The screws, which are at the base of the powdered-coal bin, carry the coal at a uniform rate to the feeder pipes, where it is thoroughly mixed with air by agitator wheels attached to the end of the screw shaft. From the paddlewheel the fuel is carried into the furnace by the air blast supplied from the blower. The latter is comparatively small and does not begin to supply all the air required for complete combustion, about 95 per cent of the air being induced by the stack through dampered openings provided at the front of the furnace. In the present installation there are twelve 10½-in. openings, all or part of which are used according to the requirements.

The boiler is a three-pass vertically baffled Edge Moor, provided with three drums. The furnace was originally installed in 1898 for burning bituminous coal and had approximately 70 sq. ft. of grate area in an underfeed stoker. The boiler has 4,685 sq. ft. of steam-making surface and is equipped with a superheater. Very little remodeling of the setting was necessary. A mixing oven extending a short distance in front of the boiler was provided and the inner corner formed by the floor of the ashpit and the bridge-wall was rounded out, the ashpit thus being utilized as combustion space. The burner is placed at the top of the furnace, discharging the coal downward. Its height is such that the flame lacks 5 or 6 ft. from coming in contact with the floor of the ashpit, so that the ashes drop through a relatively cooler zone and form a light powder which, with small slugs of slag, is raked out through the door at the bottom into a bucket conveyor provided for its removal.

The furnace volume is approximately 1,700 cu. ft., allowing at normal rating of the boiler slightly less than 1 cu. ft. of volume per pound of coal burned per hour. The furnace, however, will give just as efficient results at 200 to 300 per cent of rating, so that the ratio, perhaps, might be better described as 4 cu. ft. of furnace volume per 100 sq. ft. of steam-making surface. The coal feeders and burners are of the "Lopulco" type.

As to the operation of this system and the results obtained in the official acceptance test, the following comments were made by John Anderson, chief engineer of power plants for the Milwaukee Electric Railway and Light Co., before a meeting of railway stationary power-plant engineers called by the conservation section of the United States Railroad Administration. When the boiler was first put into operation a number of undesirable conditions developed. An insufficient air supply caused high furnace temperature, resulting in fusion of the ash particles and a consequent accumulation of slag between the tubes, on the furnace walls and in the ashpit. The removal of this molten slag presented a difficult problem. It was also found that the combustion chamber was originally of insufficient size, so that high gas velocities resulting from insufficient air tended toward destruction of the refractory surfaces of the furnace. The combustion chamber was therefore enlarged and a regulated air supply was provided for by means of a number of auxiliary air openings equipped with dampers. Accumulation of slag in the pit was prevented by raising the point of admission of the fuel into the furnace so that the flame lacked 5 or 6 ft. from touching the base of the pit. As a result, the particles of ash dropping from the flame did not fuse and could be easily drawn from the pit in the form of a powder and small slugs of slag. Subsequent analyses showed that the ash contained practically no carbon.

With satisfactory furnace conditions a series of preliminary efficiency and capacity tests were conducted. The brickwork was given a thorough trial by carrying the boiler at a continuous rating of 180 per cent over a period of several days. On August 12 and 13 a final efficiency test, the results of which are published herewith, was run.

Due to the nature of the equipment the coal could not be weighed on the firing floor. To arrive at exact figures it was necessary to run all drying and pulverizing equipment free of coal. The fuel in the pulverized storage bin was run to as low a level as possible and a measurement taken to determine the cubical contents of the powdered coal on hand at the start. Coal for the test run was weighed into the system at the moist-coal bunker, and, at the close of the run, the starting conditions, so far as was possible, were again established. Samples for analysis upon which the test results are based were taken at the moist-coal bunker as the coal was weighed in. Moisture samples were also taken at the feeder delivering to the pulverizer and at the burners.

During the test the feed water was weighed on standard tank scales of 2,000-lb. capacity each. All feed-pump gland leakage was accounted for in the way usually adopted in standard boiler tests. All temperatures and pressures were taken with instruments that had been previously checked with standards. The blowoff piping on the boiler was disconnected so as to insure against any possible loss of water. The flues were blown five times during the 24 hours. Flue-gas analyses were made by means of an Orsat. Throughout the test uniform conditions were maintained. The speed of the coal feeders and the draft carried were held constant. The feed-pump speed had to vary somewhat from time to time, the variation in the rate of evaporation being due to slight changes in the quality of coal during the test run.

In looking over the test data it will be noticed that an evaporation from and at 212 deg. of 9·47 lb. of water per pound of coal was obtained. The average temperature of the feed water was 157·2 deg. Fahr., the operating steam pressure 167 lb. gauge, and the superheat 74·9 deg. Fahr. The fuel used was screenings of three different varieties, which in the

tabulated test data are numbered from 1 to 3. The B.t.u. in the three lots of coal as received averaged 10,779 and the B.t.u. dry, 12,045. During the test a total of 24 tons of coal was burned, averaging one ton of coal per hour.

A noticeable feature is the small amount of draft required. There is, of course, no fuel bed and the drop through the boiler when using a relatively small volume of air is practically negligible. In the combustion chamber and the first pass the vacuum was practically nil, or at least so small that it could not be read on a gauge calibrated to 0·01 in. In the second pass the draft was 0·0057 in. and, at the uptake, 0·0975 in. It was noticeable that there was no accumulation of slag on the tubes, no pulsation, and that the brickwork was not affected by the heat of combustion.

The deductions made for fuel preparation are interesting. Under the dryer 1,140 lb. of coal was burned. The power requirements for the pulverizers, the various conveyors, the feeders and the fans were 449·3 kw.-hr., reducing on a basis of 3 lb. of coal per kilowatt-hour, to 1,348 lb. of coal. The total deduction, then, is 2,488 lb. of coal, which, at $5 per ton, would amount to $6.22. As 24 tons of coal were used in the test, the fuel value for preparation reduces to 26c. per ton.

Although no deductions were made for standby losses in the dryer, attention is called to the fact that the drying and pulverizing equipment was designed for a five-boiler plant, and that, when working to capacity, more efficient results would be obtained than from the intermittent operation made necessary in serving only one boiler.

In conclusion, Mr. Anderson gave an interesting comparison between pulverized coal equipment and mechanical stokers. In crushing the coal the expense is the same for both types of equipment. Although no daily operating records are available at present, Mr. Anderson estimates the cost of drying and pulverizing the coal at 32c. per ton on a 200-ton per 24-hour plant using bituminous coal containing about 12 per cent moisture. In the test it will be remembered that the fuel value for preparation amounted to about 26c. per ton. Daily operating figures would, of course, vary somewhat from those obtained under test conditions. Maintenance costs on the drying and pulverizing plant had not been determined, but it was estimated that 3c. per ton would cover this item. In stoker practice the maintenance cost was close to 5c. per ton of fuel fired.

With coal at $5 per ton it was estimated that the gross efficiency shown by the pulverized-fuel boilers would have to exceed that shown by the mechanical stoker-fired boilers and 6 per cent to offset the coal preparation costs. Again, a conservative allowance was made for daily operating conditions versus the test data. Deducting 6 per cent from the gross efficiency of 85·22 per cent would leave a net efficiency of 79·22 per cent for the pulverized coal burners. In stoker practice the maximum obtainable gross efficiency at any of the company's plants had been 80·54 per cent, the daily average being in the neighbourhood of 76 per cent. Deducting $2\frac{1}{2}$ per cent for auxiliary uses, which is somewhat lower than the average, the resulting net efficiency is 78·04 per cent, or 1·18 per cent lower than the figure obtained in pulverized-fuel practice.

This small gain in efficiency was only a part of the advantages resulting from the use of pulverized fuel. Other advantages Mr. Anderson summarized as follows: Continuous boiler operation at a uniform rating as well as constant efficiency. At no time is there a loss in capacity due to the clinkering of coal on grates or cleaning fires, nor are difficulties

experienced from a change in the fuel as it comes from the bunker, necessitating different operating conditions at the stoker. Heavy overloads can be taken on or dropped off in an unusually brief time through adjustment of the coal feeders and the furnace draft. From 97 to 98 per cent of the combustible in the coal is utilized regardless of the quality of the fuel. The ash-handling costs are reduced to a minimum due to the reduced volume.

When operating with pulverized fuel, the banking conditions are somewhat different from those obtained in stoker practice. By stopping the fuel supply and closing up all dampers and auxiliary air inlets, a boiler can be held up to pressure for at least ten hours. To illustrate, when running one of the preliminary tests the boiler had been shut down at 9 o'clock at night with 175 lb. steam pressure and at 7 in the morning there was still 155 lb. pressure and the brickwork was hot enough to ignite the coal from the burner. In stoker practice it is necessary to leave the damper slightly open to supply air and prevent gas explosions, so that much of the heat in the banking coal and from the brickwork passes up the stack rather than into the boiler.

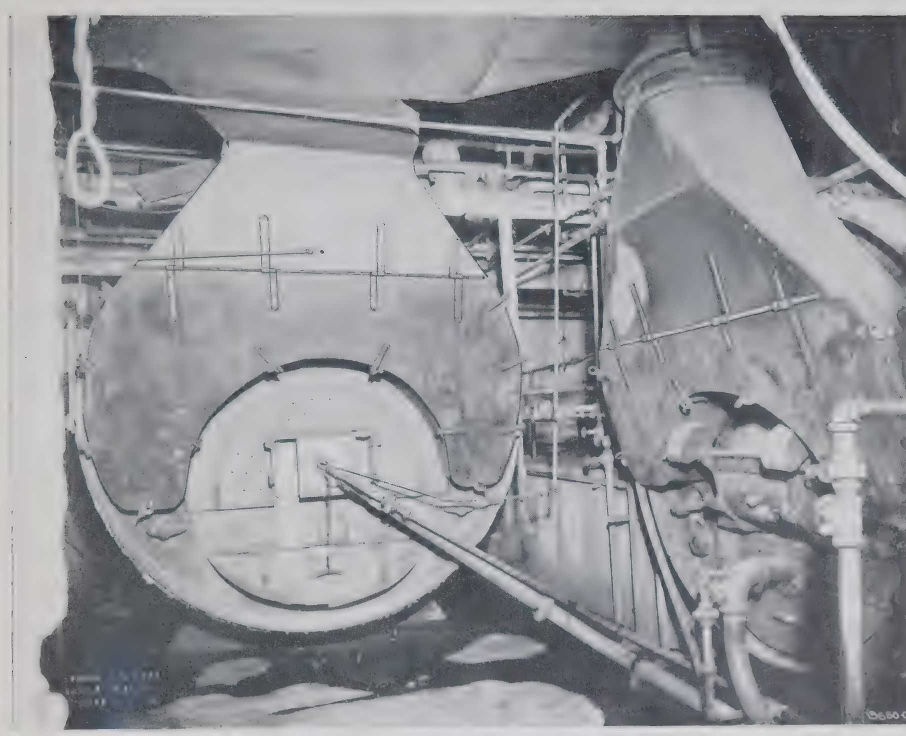
The ease of controlling the fuel feed and draft, the ability to take on heavy overloads in a brief time, the thorough combustion of the coal and the uniform high efficiency obtainable under normal operation make pulverized coal a satisfactory form of fuel for central station use. For operation month in and month out it was Mr. Anderson's opinion that pulverized fuel would show a net gain of 10 per cent over the previous way of operating.

As to maintenance, indications were that no unusual difficulties would be encountered. The cost of fuel preparation and labour for operating a boiler room fully equipped with pulverized coal-burning boilers would be a question for the engineer to determine himself, according to the particular conditions, whatever they may be in that plant. One predominant factor justifying the use of pulverized fuel was the ease with which a high efficiency could be obtained and the constant nature of that efficiency as compared to the variation in a stoker-fired boiler unless it was closely supervised. There was little doubt that, with a well-equipped plant burning pulverized fuel and having all the necessary recording and indicating instruments to guide the operator in maintaining proper conditions, a lower cost of generating steam would be possible than has heretofore been obtained with any type of equipment.

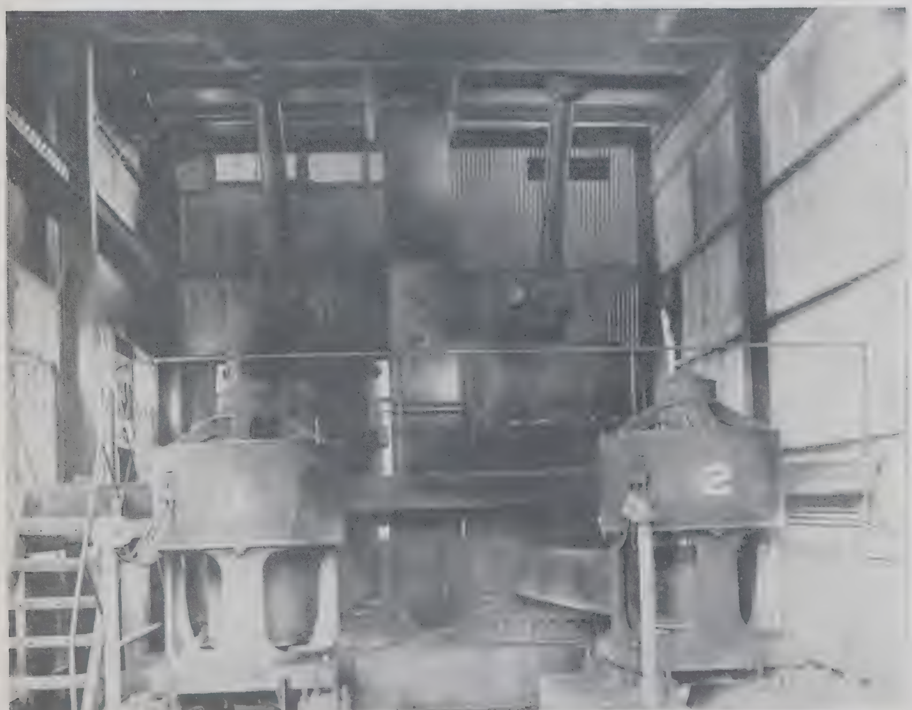
It is interesting to note that the company that Mr. Anderson represents is equipping four more boilers with the same type of apparatus. The furnace as developed is considered standard and highly efficient operation is expected. When additional information has been obtained from the complete plant and initial costs are available, data based on actual operation will be of exceptional interest.

LOG OF OFFICIAL TEST AT ONEIDA STREET STATION

Day............Monday and Tuesday	Date.................Aug. 12-13, 1918		
Make of boiler..............Edge Moor	Rated h.p......................... 468		
Heating surface, sq. ft.	4,685		
Time fired or test started	11:15 a.m., Aug. 12, 1918		
Time fired out or test finished	11:15 a.m., Aug. 13, 1918		
Duration of test, hours	24		
Temp. of boiler room, deg. F	Max. 99	Min. 85	Av. 93·30
Temp. of feed water, deg. F	Max. 188	Min. 135	Av. 157·20



SCOTCH MARINE DRY-BACK BOILERS
Capacity, 935 horse-power. New Richmond Hotel, Seattle, Wash.



MISSOURI, KANSAS AND TOPEKA RY., PARSONS, KAS.
Fuller-Lehigh pulverizer mills, for pulverizing low-grade coal for burning under boilers.

LOG OF OFFICIAL TEST AT ONEIDA STREET STATION—*Concluded*

Temp. of steam, deg. F	Max. 477	Min. 427		Av. 448·70
Barometer, inches	Max. 29·35	Min. 29·20		Av. 29·25
Temp. of flue gases, deg. F	Max. 515	Min. 455		Av. 495·30
Average boiler pressure, lbs. gauge				167·0
Atmospheric pressure, lbs				14·4
Temp. of steam, cor. to press., deg. F.				373·8
Superheat, deg. F				74·9
Safety valve set for 175 lb.				
Fuel fired per hour, lbs. 1990·6 lbs. Bituminous				100%
Total fuel, lbs.				47,775
Total water, lbs.				393,168
Water apparently evaporated per hour, lbs				16,392
Water apparently evaporated per pound of coal, lbs				8·23
Factor of evaporation				1·1502
Water evaporated f. and a. 212 deg. F., per lb. of coal, lb				9·47
CO_2, per cent, maximum	15·4	Min. 12·20		Av. 13·85
O, per cent, maximum	5·6	Min. 3·20		Ab. 4·38
CO				None
Fuel used, kind				Screenings
Fuel analyses:	No. 1	No. 2	No. 3	Av.
Moisture	10·3	11·0	9·7	10·49
Volatile	33·81	36·96	39·77	35·96
Fixed carbon	50·43	49·13	48·29	49·53
Ash	14·36	13·91	12·94	13·93
Sulphur	1·99	2·06	2·12	2·04
B.t.u. as received	10,600	10,763	11,263	10,779
B.t.u., dry	11,817	12,093	12,473	12,045
Pounds of coal	19,775	20,000	8,000	......
Percentage of total	41·3	41·9	16·8	......
Vacuum in combustion chamber				0·00
Vacuum in first pass				0·00
Vacuum in second pass, in				0·0057
Vacuum in breeching uptake, in				0·0975
Feeder speed, r.p.m.			No. 1, 53·6	No. 2, 50·7
Coal per revolution of screw, lbs				0·318
Accumulation of slag on tubes				None
Accumulation of ash in settings				Flues blown five times during test
Operation of furnace				Very satisfactory
Pulsation				None
Condition of smoke				Light
Heat effect on brick				None
Backlash of flame in burner				None
Pounds steam per hour				16,390·3
Pounds steam per hour, from and at 212 deg. F				18,842·6
Horse-power				546·2
Per cent of rating				116·7
Boiler efficiency				85·22
Memoranda: Fuel preparation deductions.				
Coal used in dryer, lbs.				1,140
Kilowatt-hour motor operation (449·3) coal equivalent at 3 lbs. per kw.-hr.				1,348
Total deduction, lbs				2,488
Resulting net efficiency, per cent				81
No deduction made for stand-by losses in dryer.				

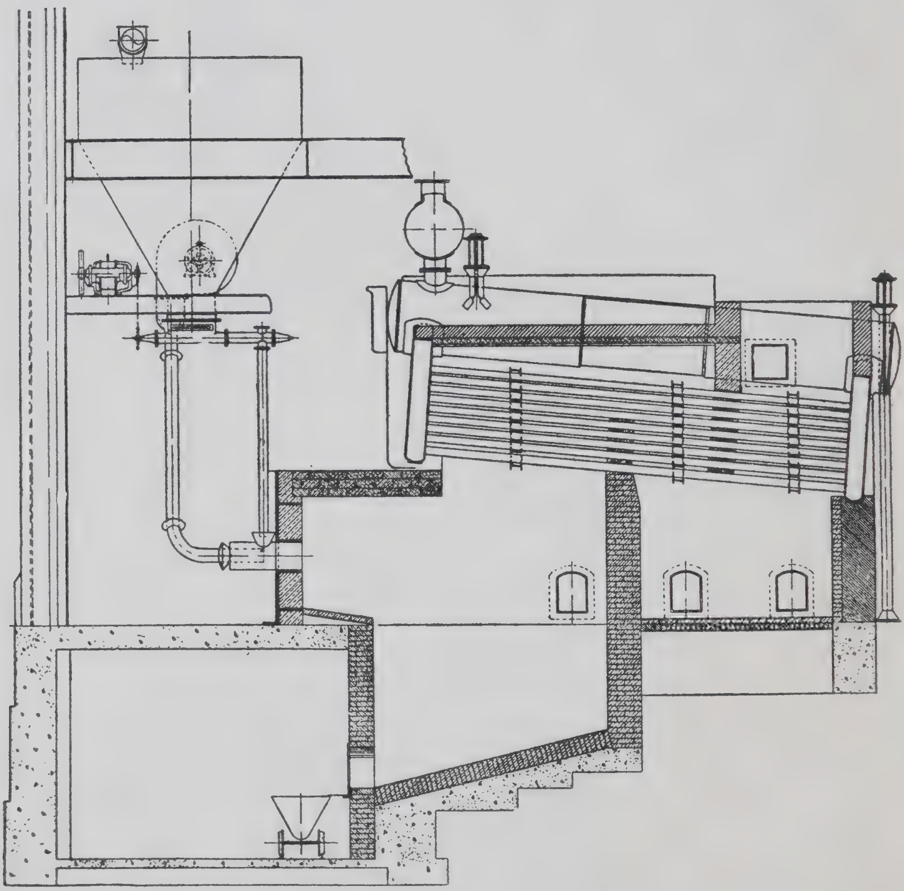
PULVERIZED FUEL INSTALLATION, PARSONS, KAN.

In 1916, the Missouri, Kansas and Texas railway installed a plant at Parsons, Kansas, for preparing and burning pulverized low-grade coals, including lignite, under boilers. This installation is stated to be the largest commercial installation of its kind in existence.

The boiler plant consists of eight O'Brien 250-h.p. boilers arranged in one continuous row of three-and-one batteries, respectively, there being a space between the settings of each pair of two boilers of 4 ft. 8 in., and a

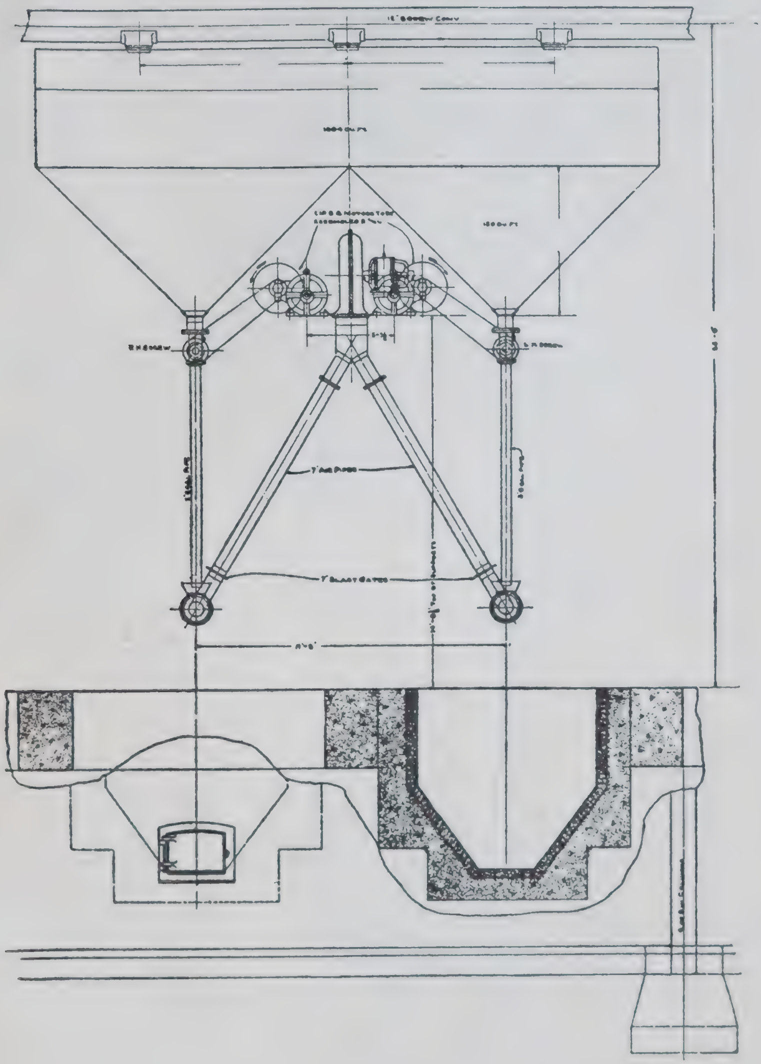
space between the two batteries of 28 ft. 4 in. for feed pumps, auxiliaries, etc. At one end space is allowed for four more boilers. The boilers carry 150 pounds per sq. in. steam pressure; the temperature of feed water is 208° Fahr. Based on a boiler efficiency of 70 per cent, operating full capacity for 10 hours, and half capacity for 14 hours, about 79 tons of coal would be consumed in 24 hours by ten boilers. When the installation is complete a total of 94 tons, per day of 24 hours, will be required. The principal advantage derived from the use of pulverized coal at this plant is that inferior grades of coal can be burned successfully, also, its use in the boiler-room reduces the number of attendants to a minimum. This reduction in labour costs partially offsets the cost of pulverizing the coal.

The following table gives the results of tests on coal from the Southern Kansas field, lignite from Texas Eastern field, and from McAlester vein.



CROSS SECTION OF 250-H. P. O'BRIEN BOILER.
Missouri, Kansas and Texas Ry. Shops at Parsons, Kans. Fired with pulverized coal, August, 1916.

The tests were made on boiler No. 1 with the furnaces as left when burning oil and gas, the cubical contents of the combustion chamber being 290 cu. ft. No. 2 boiler was changed by removing the bridge walls and increasing the combustion chamber. No. 1 boiler was again tested with lignite. Boilers 7 and 8 had combustion similar to that which is now applied to three batteries of boilers and gives very satisfactory results.



PULVERIZED FUEL INSTALLATION, PARSONS, KAS.
Showing arrangement of pulverized coal hoppers and fuel feed to boilers.

PULVERIZED COAL TESTS ON 250-H.P. O'BRIEN WATER-TUBE BOILERS AT LOCOMOTIVE SHOP POWER PLANT, M., K. & T. RY., PARSONS, KANSAS

Boiler number	No. 1	No. 1	No. 2	No. 1	No. 1	Nos. 7 & 8	No. 8	No. 8
Volume of combustion chamber (cu. ft.)	950	950	1,100	950	950	1,750	875	870
Water heating surface (sq. ft.)	2,112	2,112	2,112	2,112	2,112	3,824	1,912	1,912
Date	6–16–'16	6–21–'16	6–24–'16	7–10–'16	7–10–'16	8–7–'16	8–10–'16	8–13–'16
Duration	60 min.	124 min.	132 min.	90 min.	73 min.	84 min.	120 min.	418 min.
Kind of coal	Mineral	Lignite	McAlester	Lignite	Lignite	Mineral	Mineral	Mineral
Average fineness (gauged by 100- and 200-mesh screens).	95%–100 75%–200	95·5%–100 72·5%–200	92%–100 70%–200	96%–100 76%–200	96%–100 76%–200	95%–100 75%–200	95%–100 77%–200	95%–100 75%–200
Steam pressure by gauge, lbs	126	127·4	127	118·1	130·6	126	123	126·5
Force of draft in flue at dampers	·25	·28	·28	·262	·265	·242	·256	·23
Pressure of air in burner pipe, in.	¾	9/16	¾	⅝	¾	¾	¾	¾
Volume of air delivered by burner per min.	3,660	3,210	3,660	3,230	3,660	3,660	3,660	3,660
State of weather	Clear	Clear	Clear	Clear	Clear	Clear	Clear	Clear
Temperature of external air (Fahr.)	84°	90°	90°	98°	98°	Not	recorded	
Temperature of fire room (Fahr.)	91°	100°	95°	102·5°	106·5°	102°	100°	103°
Temperature of feed water (Fahr.)	177°	183·6°	180°	182°	182·5°	170°	187°	174·4°
Temperature of first pass (Fahr.)	810°	1,079·4°	1,388°	*	*	*	1,260°	1,950 Com. Ch. 1,476 1st pass.
Temperature of flue gases (Fahr.)	544°	491°	585°	473°	501°	470°	576·5°	446°
Quality of steam (assumed)	·99	·99	·99	·99	·99	·99	·99	·99
Proximate Analysis of Coal as Fired—								
Fixed carbon	49	32	50·1	35·4	35·4	48·7	48·7	48·7
Volatile combustible matter	28	42·5	34·3	47·1	47·1	28·4	28·4	28·4
Moisture	1	16	·5	7	7	1	1	1
Ash	22	9·5	15·1	10·5	10·5	21·9	21·9	21·9
Sulphur (separately determined)	4·7	·52	1·79	·52	·52	4·7	4·7	4·7

*Not recorded.

Total Quantities—								
Total revolutions of feed screw	2,220	5,056	4,092	3,991	3,681	7,750	7,794	14,480
Average pounds dump per revolution	·457	·3812	·501	·4375	·4375	·457	·457	·457
Total coal as fired	1,014	1,927	2,062	1,746	1,612	3,540	3,560	6,617
Total dry coal consumed	1,004	1,620	2,051	1,623	1,500	3,500	3,525	6,560
Total combustible consumed	781	1,437	1,739	1,440	1,330	2,730	2,745	5,100
Total water fed to boiler	6,000	13,000	17,000	12,000	11,000	22,700	23,200	51,700
Total water evaporated (corrected)	5,940	12,880	16,820	11,900	10,900	22,490	22,980	51,200
Factor of evaporation	1·0795	1·0728	1·0764	1·0736	1·0743	1·0867	1·06875	1·0822
Total equivalent evaporation from and at 212° Fahr.	6,420	13,818	18,105	12,770	11,710	24,444	24,560	55,400
Hourly Quantities and Rates—								
Dry coal consumed per hour	1,004	784	933	1,082	1,231	2,500	1,762·5	956
Combustible consumed per hour	781	695	790	960	1,093	1,950	1,372·5	733
Pounds of combustible per minute	13	11·6	13·2	16	18·2	32·5	22·9	12·2
Cu. ft. of comb. chamber per lb. of comb. per minute	73·2	81·8	75·8	59·3	52·2	54	38·2	71
Water evaporated per hr. (corrected)	5,940	6,230	7,650	7,940	8,960	16,050	11,490	7,350
Equiv. evap. per hr. from and at 212° Fahr.	6,420	6,690	8,240	8,520	9,530	17,450	12,280	7,950
Equiv. evap. per hr. from and at 212° Fahr. per sq. ft. of water heating surface.	3·035	3·17	3·9	4·03	4·56	4·56	6·42	4·16
Calorific Values and Capacity—								
Calorific value of 1 lb. of dry coal	11,580	11,250	12,630	11,250	11,250	11,580	11,580	11,580
Calorific value of 1 lb. of combustible	14,750	12,700	14,920	12,680	12,680	14,880	14,750	14,750
Equiv. evap. from and at 212° Fahr	6,420	6,690	8,240	8,520	9,530	17,450	12,280	7,950
Boiler horse-power developed	186	194	230	247	275	506	356	230·5
Rated boiler horse-power	250	250	250	250	250	500	250	250
Percentage of rated capacity developed	74·4	77·6	95·6	98·9	110	101	142	92·2
Economy Results—								
Water fed per pound of coal as fired	5·92	6·75	8·24	6·88	6·82	6·41	6·52	7·81
Water evaporated per pound of dry coal	5·92	6·94	8·20	7·33	7·27	6·43	6·52	7·80
Equiv. evap. from and at 212° Fahr. per lb. of coal as fired	6·32	7·17	8·77	7·31	7·26	7·18	6·90	8·38
Equiv. evap. from and at 212° Fahr. per lb. of dry coal	6·38	8·54	8·85	7·86	7·81	7·27	6·97	8·46

PULVERIZED COAL TESTS ON 250-H.P. O'BRIEN WATER-TUBE BOILERS AT LOCOMOTIVE SHOP POWER PLANT, M. K. & T. RY., PARSONS, KANSAS—*Continued*

Boiler number	No. 1	No. 1	No. 2	No. 1	No. 1	Nos. 7 & 8	No. 8	No. 8
Equiv. evap. from and at 212° Fahr. per lb. of combustible	8·22	9·62	10·40	8·86	8·81	8·95	8·95	10·90
Efficiency of boiler and furnace	53·9	73·5	67·8	67·8	67·4	61·0	59·0	71·5
Cost of Evaporation—								
Cost of pulverizing per 2,000 lbs.	$0·35	$1·17	$0·34	....	....	$0·35	$0·35	$0·35
Total cost of coal per 2,000 lbs. delivered to boiler bins	$1·795	$5·57	$2·609	....	....	$1·795	$1·795	$1·795
Cost of evaporating 1,000 lbs. of water, observed conditions	$0·153	$0·481	$0·160	....	....	$0·141	$0·139	$0·116
Cost of evaporating 1,000 lbs. of water, from and at 212° Fahr.	$0·142	$0·388	$0·148	....	....	$0·125	$0·130	$0·083
Analysis of Dry Flue Gases—								
Carbon dioxide	12	10	10	10	12·5	10	13·5	10·7
Oxygen	8	10	9·5	11	8·5	11	7·5	9·3
Carbon monoxide	0	·5	0	0	0	0	0	0
Nitrogen (by difference)	80	79·5	80·5	79	79	79	79	80
Heat Balance (Based on 1 lb. of dry coal) Percentage—								
Heat absorbed by the boiler	53·6	73·6	67·8	67·8	67·3	61·0	59·0	71·5
Loss due to evaporation of moisture in coal	·1	1·7	·1	·8	·7	....	....	·3
Loss due to heat carried away by steam from hydrogen	5·1	4·0	4·0	4·7	4·8	....	....	3·8
Loss due to heat carried away by dry flue gases	11·4	13·3	16·2	13·7	11·8	....	....	10·8
Loss due to carbon monoxide	0	·3	0	0	0	....	....	0
Loss due to radiation and losses unaccounted for	29·7	7·1	11·8	13·1	15·4	....	....	13·6
TOTAL = Calorific value of 1 lb. of dry coal	11,580	11,250	12,630	11,250	11,250	11,580	11,580	11,580

Pulverizing Plant

The coal is dumped directly from the cars into a concrete-and-steel hopper beneath the track. As a large percentage of the coal is run-of-mine the coal from the hopper is crushed by a 20 x 24-in. spike-toothed roll crusher. From the crusher the coal is elevated by a 20-in. belt conveyor through an inclined tunnel and discharged into the coal plant. At the discharge end of the conveyor the coal is passed through a magnetic separator and discharged into a pair of 28 x 18-in. corrugated rolls. From the rolls the crushed coal is elevated, discharged into a screw conveyor and carried to a 40-ton bin situated at the back end of the dryer. From the bottom of the bin the coal is fed by screw-conveyor to the back end of a $4\frac{1}{2}$ x 30-foot indirect-fired rotary dryer. From the dryer the coal is elevated and discharged into a 45-ton bin situated over the pulverizers. The pulverizing plant consists of two 75-ton pulverizing mills, furnished by the Fuller Company. From the mills the pulverized coal is elevated and conveyed by screw-conveyor to bins in the boiler house. One bin is situated in front of each pair of boilers. The bins have a capacity of 10 tons each and, therefore, provide for a run of 20 hours at full capacity. The bins are rectangular, but have divided hopper-bottoms, thus enabling the coal to be fed by separate feeders to each boiler. Each feeder is chain-and-sprocket driven by a 2-h.p. variable speed motor, the control of which is situated in a convenient position in front of the boilers. The coal is discharged from each feeder, through a 3-inch pipe, into a funnel-shaped opening in the top of the burner nozzle. The burner consists of an outside cylindrical pipe, 14 inches in diameter, one end of which projects into the furnace; a 7-inch blast pipe is inserted in the other end for a distance of from 12 to 18 inches. An adjustable metal cover is fitted over the blast pipe so as to regulate the amount of air induced in the burner. The funnel-shaped opening into which the coal is fed is directly over the discharge end of the blast pipe, so that the coal will be drawn in and thoroughly mixed with the blast and induced air before reaching the combustion chamber of the furnace.

The boilers were installed as shown on plate facing page 43, but, on account of the high ash content (22 per cent) in the coals used, it was found that, with horizontal baffles, there was too much ash accumulation; so a Dutch oven, approximately of 6-feet cube, has since been built in front of the boilers; also, vertical baffles were inserted, replacing the former horizontal ones. With these changes highly gratifying results are obtained; no slag is formed, and the ash is readily blown off the floor of the rear chamber with an air hose once a week.

Missouri, Kansas and Texas Railway

Mr. W. A. Webb, chief operating officer of the power plant of the Missouri, Kansas and Texas railway, at Parsons, Kansas, in reply to enquiries, makes the following statements regarding the use of pulverized fuel:

"The advantage of pulverized fuel is the utilization of fuel that is recoverable in pulverized form, and the use of inferior grades which can be burned successfully when mixed with better grades. The use in boiler rooms of pulverized fuel reduces the attendants to a minimum, and this reduction in labour costs partially off-sets the cost of pulverizing the coal.

"We attach blue-print which gives test on mineral coal furnished from Southern Kansas field; lignites from Texas Eastern field and McAlester, from McAlester vein, which covers all the tests of fuel we have made. This shows first two tests on boiler No. 1, as the furnaces were left burning oil and gas, having cubical capacity of combustion chamber of 950 cubic feet. No. 2 was changed by removal of bridge walls and increasing combustion chamber. No. 1 boiler was again tested with lignite, in which percentage was figured on. Boilers 7 and 8 show combustion chamber as it now exists and as applied to three batteries of boilers. It is working satisfactorily.

"The plant consists of two 75-ton pulverizing mills, furnished by Fuller Company, drying kiln and necessary conveyors and storage bins in power-house; all working automatically, from the unloading of coal into receiving bin until deposited in storage bins ready for use. From this storage bin a screw operated by motor feeds coal to burner at the rate of approximately one-half pound of coal per revolution. A fan is also operated by motor giving blast at about one ounce pressure or less. Burner consists of galvanized pipe into which air is projected and the coal drops from vertical feed and distributed by blast from fan into combustion chamber. Leading from this combustion chamber to a point below the floor line of boiler is a receptacle for slag, from which same is removed for final disposition.

"Some time ago we equipped one of our locomotives for burning pulverized fuel. This equipment consists of a closed tank for carrying the pulverized fuel, which is fed by screw to burner situated below mud-ring of boiler blower and screw operated by steam turbine contained in tank. The fire-box is bricked with primary arch for initial burning and flame is conveyed to regular arch, is again brought into contact with vertical side-walls and thence to center wall and finally strikes flue sheet.

"Considerable trouble has been experienced with slagging and stopping up of flues, and these vertical walls are for protecting the flues from this slagging. With one test of lignite coal of Texas grade no slagging occurred. This engine has not passed experimental stages and tests so far conducted are not conclusive."

Chicago and Northwestern Railway

Mr. R. Quayle, General Superintendent of Motive Power, in a letter to the author regarding pulverized fuel for steam raising in stationary boiler plants and locomotives, states:

"We did operate for a number of months an Atlantic type locomotive between Chicago and Milwaukee, and I am attaching hereto blue-print

giving the result of such operation. I am also sending a blue-print giving a general description of the engines used.

"These two engines were of the same type, built at the same time, and, if anything, the one without the pulverized-fuel device on was a little the smarter engine; in fact, we selected the best engines we had in this class to work against the engine burning pulverized coal, so that if there was any advantage it would be a decided advantage.

"We were unable to successfully run more than 75 or 80 miles with Illinois coal, because it contains a good deal of sulphur and iron pyrites and 10 per cent, or more, of moisture. After running about 80 miles the flue sheet would begin to plaster over, and then the steam pressure would begin to diminish. After we had obtained about 100 miles we would begin to lack for steam.

"We used Kentucky coal, however, in other tests and we had no difficulty whatever. I understand from the Pulverized Fuel Co., 30 Church street, New York, that they are now able to burn pulverized Illinois coal, such as we first used, without the flue sheet plastering over.

"We were able to get approximately 18 per cent saving in fuel. We did not have to put the engine over the clinker pit at all, because the fuel consumed in the distance of 80 miles left only two lumps of slag, one on either side of the ash pan, each equivalent in size to that of an ordinary derby hat.

"Our pulverizing plant was just a temporary affair. The engine, however, was fitted up in the latest style. The pulverizer itself was home-made, as was also the dryer. We had intended to have this plant enlarged to take care of ten new switch engines and try out the use of pulverized fuel on them in a district here in Chicago where we have much switching to do and where smoke is a great nuisance, *i.e.*, our Municipal Pier district. This is a very high-class residential district. But, recently, on account of financial and other matters, the change was held up, for the present at least."

CHICAGO AND NORTHWESTERN RAILWAY—COMPARATIVE LOCOMOTIVE TESTS

CHICAGO-MILWAUKEE-CHICAGO. CLASS D. ENG. 128, SUPERHEATER, PULVERIZED COAL BURNER, WALSCHAERT VALVE GEAR — KENTUCKY COAL

Date, 1916.	Time, hours		Avg. temp., atmo.	Tonnage		Mileage		Total mile-age	Coal used, tons	Coal used, -pounds		Water used, gallons	Water used, pounds		Pounds of water evapo-rated per lb of coal	Average draw-bar pull, pounds	Work done, horse-power, per hr.	Number of cars	
	Elapsed	Running		Chicago-Milwaukee	Milwaukee-Chicago	Chicago-Milwaukee	Milwaukee-Chicago			Per hour	Per horse-power per hour		Per hour	Per horse-power per hour				Chicago-Milwaukee	Milwaukee-Chicago
Mar. 21...	4·0916	3·8874	40·5	355	252	84·72	86·07	170·79	3·984311	2,049·859	6·307	8,787·5	18,830·034	57·934	9·186	2,770·811	325·028	7	5
Mar. 30...	3·9625	3·8500	47·4	303	252	84·69	86·00	170·69	3·646490	1,894·281	6·034	7,975·0	17,255·000	54·967	9·108	2,651·891	313·916	6	5
Average...	4·0276	3·8687	43·9	329	252	84·75	86·04	170·74	3·81540	1,972·446	6·173	8,381·25	18,046·324	56·834	9493·149	2,711·351	319·497	6·5	5

CLASS D. ENG. 127, SUPERHEATER, HAND FIRED, WALSCHAERT VALVE GEAR, KINGAN & RIPKEN ATTACHMENT

CHICAGO-MILWAUKEE-CHICAGO — ILLINOIS LUMP COAL

Mar. 23...	3·9625	3·7750	35·2	355	252	84·78	86·08	170·86	5·5900	2,961·589	9·039	8,175·0	18,039·139	55·055	6·091	2,711·351	327·657	7	5
Mar. 24...	3·9583	3·8792	48·8	355	252	85·18	86·07	171·25	4·7875	2,468·292	7·723	7,350·0	15,783·022	49·386	6·394	2,711·351	319·584	7	5
Average...	3·9604	3·8271	42·0	355	252	84·98	86·08	171·06	5·18875	2,711·583	8·380	7,762·5	16,895·724	52·215	6·230	2,711·351	323·575	7	5

CLASS D. ENG. 127, SUPERHEATER, HAND FIRED, WALSCHAERT VALVE GEAR, KINGAN & RIPKEN ATTACHMENT

CHICAGO-MILWAUKEE-CHICAGO — KENTUCKY LUMP COAL

Mar. 29...	3·9833	3·8625	43·9	303	252	84·77	86·13	170·90	3·6315	1,880·388	6·168	7,062·5	15,231·229	49·962	8·100	2,530·540	304·856	6	5
Mar. 31...	4·2083	4·0750	59·6	303	252	84·68	85·92	170·60	3·9340	1,930·798	6·983	7,637·5	15,612·362	56·466	8·085	2,478·514	276·488	6	5
Average...	4·0958	3·9688	51·7	303	252	84·72	86·03	170·75	3·78275	1,906·243	6·567	7,350·0	15,426·703	53·144	8·092	2,527·027	290·283	6	5

ACTUAL AND PERCENTAGE COMPARISON OF COAL AND WATER USED

Classes	Coal used, tons		Coal used, pounds, per h.p. per hour		Water used, gallons		Water used, pounds per h.p. per hour		Work done, h.p. per hour		Pounds water evaporated per pound coal		Coal used "firing up" round-house to train and return, "dead time"		Total tons of coal used	
	Tons coal	Per cent	Pounds coal	Per cent	Gallons water	Per cent	Pounds water	Per cent	Horse-power	Per cent	Pounds water	Per cent	Tons coal	Per cent	Tons coal	Per cent
D. 127, Ill. coal, superheat, Wal. gear, Ripken attach.	5·18875	100	8·380	100	7,762·5	100	52·215	100	323·575	100	6·230	100	2·675	100	7·86375	
D. 127, Kentucky coal, superheat, Wal. gear, Ripken attach.	3·78275	72·92	6·567	78·37	7,350·0	94·69	53·144	101·78	290·283	89·71	8·092	129·89	2·775	103·73	6·55775	83·39
D. 128, Kentucky coal, superheater, pulverized coal.	3·81540	73·53	6·173	73·66	8,381·25	107·97	56·483	108·17	319·497	98·74	9·149	146·85	1·5690	58·65	5·38400	68·47

CHICAGO, C. & N. W. RY., APRIL 7, 1916.

Delaware and Hudson Railroad

The Delaware and Hudson railroad has, in freight service, a consolidation locomotive (probably the largest of this type in the world) equipped to burn pulverized fuel. The locomotive was designed for the use of anthracite culm, but it is understood that a mixture of bituminous and anthracite coal is being used. The locomotive has 63-inch driving wheels, 27 x 32-inch cylinders, 12-inch piston-valves and a boiler with a working pressure of 195 pounds[1] per square inch. The diameter of the boiler at the front end is 86 inches and a fire box 114 inches by $126\frac{1}{16}$ inches provides a grate area of 99·8 square feet. Total weight, 293,000 pounds; weight on drivers, 267,000 pounds; total heating surface, 3,814 square feet; traction power, 66,100 pounds. The superheater has 43 elements and a heating surface of 793 square feet. The tender is of the 8-wheel type, with water capacity of 9,000 gallons, fuel capacity of $14\frac{1}{2}$ tons, and weighs, in working order, 193,200 pounds.

The locomotive was built specially for use with pulverized fuel by the American Locomotive Co., and was equipped with the apparatus of the Locomotive Pulverized Fuel Co., New York.

The following is the result of tests on this locomotive:

Class of locomotive	2–8–0
Number of trips averaged	11
Miles run, average each trip	19·9
Adjusted train ton miles	49,686
Total water used, pounds	52,975
Total coal used	11,028
Boiler pressure, pounds per square inch	205
Average steam pressure, per square inch	192
Apparent evaporation	4·84
Lbs. of coal used per 1,000-ton miles	221·9
Lbs. of coal used per engine mile	552·9
Average speed, miles per hour	11·7
Service	Freight
Diameter of exhaust nozzle, inches	6½

The temperature of the water at start was 200° and the time taken to obtain maximum pressure was 45 minutes.

The kind of coal used was a mixture of 60 per cent anthracite and 40 per cent bituminous. The following is an analysis of the mixture:

Moisture	0·36	per cent
Volatile matter	20·73	"
Fixed carbon	62·65	"
Ash	16·26	"
	100·00	"
Sulphur	1·00	per cent
British thermal units	13,000	

Fineness of pulverized coal:

Percentage through 100-mesh screen	99
Percentage through 200-mesh screen	89

[1]The pressure has been increased to 210 pounds per square inch.

NEW YORK CENTRAL RAILROAD

So far as known the New York Central railroad was the first to equip and successfully operate, in regular train service, a locomotive having a self-contained equipment for burning pulverized coal in suspension. At the present time this railway is using fuel in small amounts on one locomotive, the policy being to develop the use of pulverized fuel as an alternative to the use of fuel-oil in territory in the forest reserve, where oil is at present required. The following is a result of tests carried out on this locomotive:

Class of locomotive	4–6–2
Number of trips averaged	28
Miles run, average each trip	78·6
Adjusted train ton miles	125,956·0
Total water used, pounds	94,850·0
Total coal used, pounds	12,730·0
Boiler pressure, pounds per square inch	180
Average steam pressure, pounds per square inch	174·8
Apparent evaporation	7·45
Pounds of coal per 1,000-ton miles	101·0
Pounds of coal per engine mile	161·9
Average speed in miles per hour	21·8
Service	Freight
Diameter of exhaust nozzle, in inches	6¼

The temperature of water at start was 120° and the time taken to obtain the maximum pressure of steam was 72 minutes.

The tests were carried on with bituminous coal obtained from five mines and having the following average analysis:

Moisture	0·85	per cent
Volatile matter	27·25	"
Fixed carbon	61·68	"
Ash	10·22	"
	100·00	"
Sulphur	1·96	per cent
British thermal units	13,975	"
Fineness of pulverized coal:		
Through 100-mesh screen	96	per cent
Through 200-mesh screen	81	

The following is a brief description of this locomotive:

Type	4–6–2
Cylinders	26 x 26 inch.
Driving wheels	69 inches in diameter.
Boiler pressure	180 pounds per square inch.
Total weight	266,000 lbs.
Weight on drivers	172,000 lbs.
Total heating surface	3,769·6 sq. ft.
Grate area (nominal)	56·5 sq. ft.
Tractive power	38,980 lbs.

CENTRAL RAILWAY OF BRAZIL

In Brazil, owing to the difficulty of obtaining high-grade coal as fuel and the necessity for using the low-grade coal which occurs there, the Central Railway of Brazil, after considerable investigation of the pulverized-fuel-burning locomotives, decided to equip its locomotives for burning

fuel in this form. It is reported that the burning equipment is to be practically a duplicate of that installed on the consolidation locomotive of the Delaware and Hudson railroad.

Twelve locomotives, having the following description, are to be equipped for burning pulverized coal: Type, 4–6–0; cylinders, 21½ in. x 28 in.; driver wheels, 68 in.; boiler pressure, 175 lbs. per sq. in.; total weight, 172,000 lbs.; weight on drivers, 122,000 lbs.; total heating surface, 2,151 sq. ft.; grate area (nominal), 30 sq. ft.; tractive power, 28,400 lbs. The engines are equipped with a two-burner equipment and the tender has a fuel capacity of 12 tons. The pulverizing plant is not installed, as yet, but will include two A–8 dryers, and two 57-inch pulverizer mills, having a capacity of 8 tons per hour each.

The fuel to be utilized is Brazilian coal, having approximately the following analysis:

Moisture	0·5 per cent
Volatile matter	32·3 "
Fixed carbon	42·1 "
Ash	25·1 "
	100·0 "
Sulphur	2·35 per cent
British thermal units	11,112

PEAT–POWDER AS LOCOMOTIVE FUEL[1]

Sweden possesses vast peat deposits, and, with coal at its present price, it is but natural that the state railways should endeavour to make use of them. Experiments have, therefore, been made with the fuel on a freight locomotive, of which the following are the particulars:

Cylinders—diameter	$19\frac{5}{8}$ in.
" stroke	25 in.
Wheels, driving (eight-coupled)	54 in.
Steam pressure	170 lb.
Heating surface—Fire-box	115 sq. ft.
" Tubes	996 sq. ft.
Superheater tubes	301 sq. ft.
Number of tubes—(1·97–1·58 in.)	118
" (5·15–4·8 in.)	18
Length between tube plates	13 ft. 1 in.
Tractive force $\frac{0{\cdot}65\ p\ d^2}{D} \times 1$	9 tons (metric)
Adhesion weight (per axle)	11·2 tons
Weight of locomotive	51 tons (metric)
Weight of tender	36 tons (metric)
Weight of water	14 tons (metric)
Weight of peat-powder	4 tons (metric)

The peat-powder is carried on the tender in a hopper with a conical bottom. Beneath the bottom is a pipe, through which the peat-powder is blown to a nozzle opening into the fire-box by means of air, compressed by a steam-blower. By firebrick partitions the fire-box was subdivided into an

[1] *Engineering*, October 20, 1916.

ignition chamber, two side passages and an upper chamber, through which the products of combustion pass and are led to and fro before they enter the tubes. For the ignition of the peat-powder there is, under the nozzle through which the peat is blown, a small grate carrying a coal fire. The consumption of coal for this purpose averages 3 to 4 per cent of the weight of the peat-powder.

The ordinary exhaust nozzle in the smoke-box did not work satisfactorily with peat-powder, and therefore had to be modified. A spark catcher was unnecessary, as the sparks are so small and light that they are extinguished before they reach the ground. As a matter of fact there are no sparks at all from the peat-powder when the firing is properly attended to.

As the result of some previous experiments, 1·4 pounds of peat-powder were considered to possess equal heating value to 1 pound of British coal. To arrive at a more accurate and definite result, these tests were undertaken, the locomotive in question having been in use for some time. The tests were made on the Hallsberg-Mjölby section (60 miles) between two locomotives of the same type, peat-powder being used in the one and coal in the other. The specifications for these tests stipulated for a freight train of 700 tons weight being run at normal service speed, which was taken as averaging 22 miles per hour. The train was to consist of cars loaded with coal, and each type of locomotive was to make three journeys. An alteration was made at the last journey, when the train was composed of bogie passenger carriages, the weight being 300 tons, and the average speed being 34 miles per hour. On the test section there is, over a distance of 3·6 miles, a rising gradient of 1 per 100, with numerous small curves with radii of from 1,000 to 1,500 feet. The speed was here reduced to 8½ miles per hour for the freight train and to about 20 miles for the passenger train. Steam pressure and water level in the boiler could, it was proved, be maintained through the whole of this gradient.

The consumption of water was read from a scale fitted to the tender tank; the results consequently include the losses from the starting of the injector and the consumption of the steam-worked blower on the peat-powder locomotive. The consumption of fuel was recorded by weighing before and after each half of a journey. To ascertain the heating values, samples of the fuel were taken on each journey. The results gave an average of 7,920 B.t.u. for the peat-powder and 13,030 for the coal. The analyses showed the following results:

	Peat	Coal
Carbon	47·0	73·5
Oxygen	29·5	4·4
Hydrogen	4·5	8·6
Sulphur	0·5	1·5
Nitrogen	1·1	1·2
Ash	3·2	6·2
Water	14·2	4·6

As the consumption of water and the heat transmitted to the steam were not the same on the two comparative journeys (*see* table), the consumption of fuel per 1,000 train-kilometres was reduced to the same water consumption and heat transmission. Some allowance must also be made for the fact that the locomotive with coal-fuel was quite new, whilst the other had been in use for some time, and therefore was less favourably conditioned.

The annexed table shows the most important results of the tests. It will be noted the superheat temperature of the steam is higher with the locomotive fed with peat-powder fuel than with the one with coal. This is owing to the fact that peat-powder burns with a longer flame than coal, and to the temperature of the products of combustion in the former case being higher than in the latter. A calculation of the boiler efficiency and the temperature of the fire-box gives, for the locomotive for peat-powder, respectively, 73 per cent and 1,670° Cent., and, for the locomotive for coal, 68·8 per cent and 1,510° Cent. Both figures, it will be seen, are higher for the former, which again signifies that the heating value of the peat-powder is better utilized than that of the coal. The main object of the tests was to ascertain the consumption of peat-powder as compared with that of coal for the production of the same quantity of steam and in doing the same work. To attain this, it was necessary to reduce the observed steam production per kilogramme of fuel to what it would have been with the same total heat content, taking as standard the total heat of steam at 190° Cent., reckoned as 665 calories. The calorific value of the fuel also had to be referred to a proper standard, and 7,740 B.t.u. was chosen for the peat-powder, and 12,600 B. t. u. for the coal. The reduced values will be found in the table annexed. In reducing the figures for the coal-fired locomotive, regard has been had to the fact that the locomotive was a new one, wherefore its efficiency was somewhat modified. Tests have shown that locomotives of this type, on an average, give about 6·3 pounds superheated steam per pound of coal; a re-calculation gives an efficiency of 0·65 instead of 0·685, which has been taken into consideration.

The final result deduced from the table is this, that the same quantity of steam can be obtained from $\frac{6.81}{4.71} = 1 \cdot 45$ pounds of peat-powder as from 1 pound of coal, when the respective values are 7,740 B.t.u. and 12,600 B.t.u., and the boiler efficiency is, respectively, 0·73 and 0·65.

With a supply of four tons of peat-powder, which the tender can hold, a freight train of 650 tons and a passenger train of 300 tons behind the tender can be hauled, respectively, 62 and 81 miles.

Fuel	Trip	Direction	Weight, in tons: Locomotive, tender and carriages	Weight, in tons: Carriages	Number of axles	Consumption, in kilogrammes: Water	Consumption, in kilogrammes: Coal	Consumption, in kilogrammes: Peat-powder	Consumption, in kilogrammes, per 1,000 train-kilometres, including locomotive and tender: Coal: Observed	Consumption, in kilogrammes, per 1,000 train-kilometres, including locomotive and tender: Coal: Reduced to standard	Consumption, in kilogrammes, per 1,000 train-kilometres, including locomotive and tender: Peat-powder	Steam pressure, atmospheres	Temperature of steam, deg. Cent.	Total heat of steam	Temperature in smoke-box, deg. Cent.	Draught in millimetres (water gauge): Fire-box	Draught in millimetres (water gauge): Smoke-box	Heating value: Peat-powder	Heating value: Coal	Kilogrammes of steam per kilogramme of fuel: Real: Peat-powder	Kilogrammes of steam per kilogramme of fuel: Real: Coal	Kilogrammes of steam per kilogramme of fuel: Reduced: Peat-powder	Kilogrammes of steam per kilogramme of fuel: Reduced: Coal	Average speed, kilometres per hour
Peat powder.........	I	H M M H	787	700	78	12,600 9,600	80 68	2,712 2,277	....	....	37·5 31·4	12·1	332	740	255	20	86	7,808	......	4·25	....	4·69	....	29·2
Coal................	II	H M M H	782	700	78	12,550 9,350	1,855 1,351	....	24·8 18·1	25·6 19·1	....	11·5	293	719	290	14	47	......	12,924	....	6·83	....	6·83	27·5
Coal................	III	H M M H	782	700	78	13,300 11,000	2,021 1,609	....	27 21·5	27·7 23·4	....	11·6	300	723	312	22	60	......	13,284	....	6·7	....	6·55	28·7
Peat-powder..........	IV	H M M H	787	700	78	13,250 11,750	87 76	2,947 2,550	....	....	40·7 35·2	11·9	336	742	294	..	....	7,880	......	4·35	....	4·77	....	27·0
Peat-powder.........	V	H M M H	387	300	40	9,400 8,700	61 58	2,016 1,940	....	....	56·9 54·6	11·8	331	740	289	15	101	8,078	......	4·38	....	4·67	....	42·3
Coal................	VI	H M M H	382	300	40	8,900 7,800	1,312 1,067	....	35·8 29·1	39·0 33·1	....	11·5	298	722	268	16	52	......	12,880	....	7·0	....	7·05	41·7
Average.......	......	......	....	....	..	....	......	......	......	......	......	....	....	....	....	..	....	7,933	13,030	4·33	6·84	4·71	6·81	....